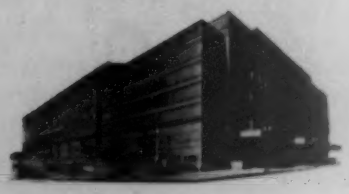
MAY 1955

THE WELDING JOURNAL

1955 WELDING SHOW
AND SPRING TECHNICAL MEETING



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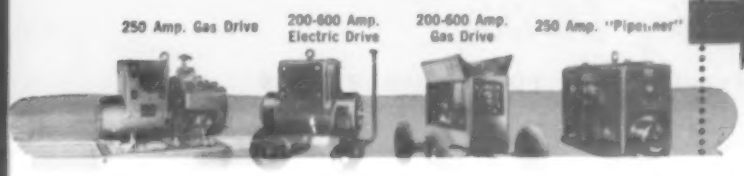

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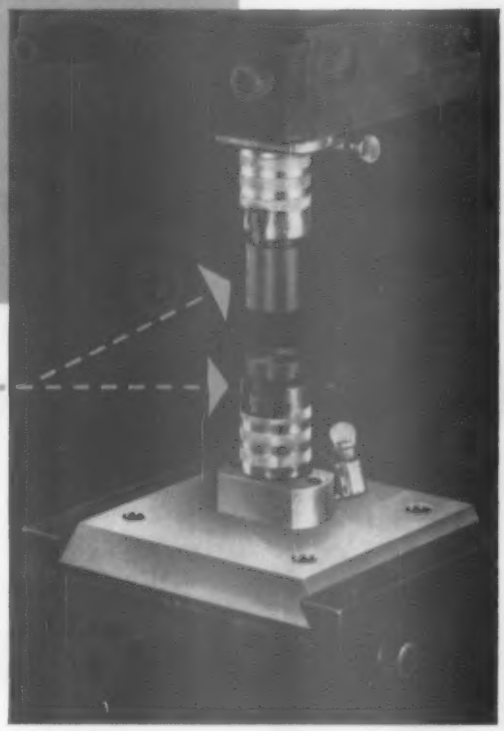

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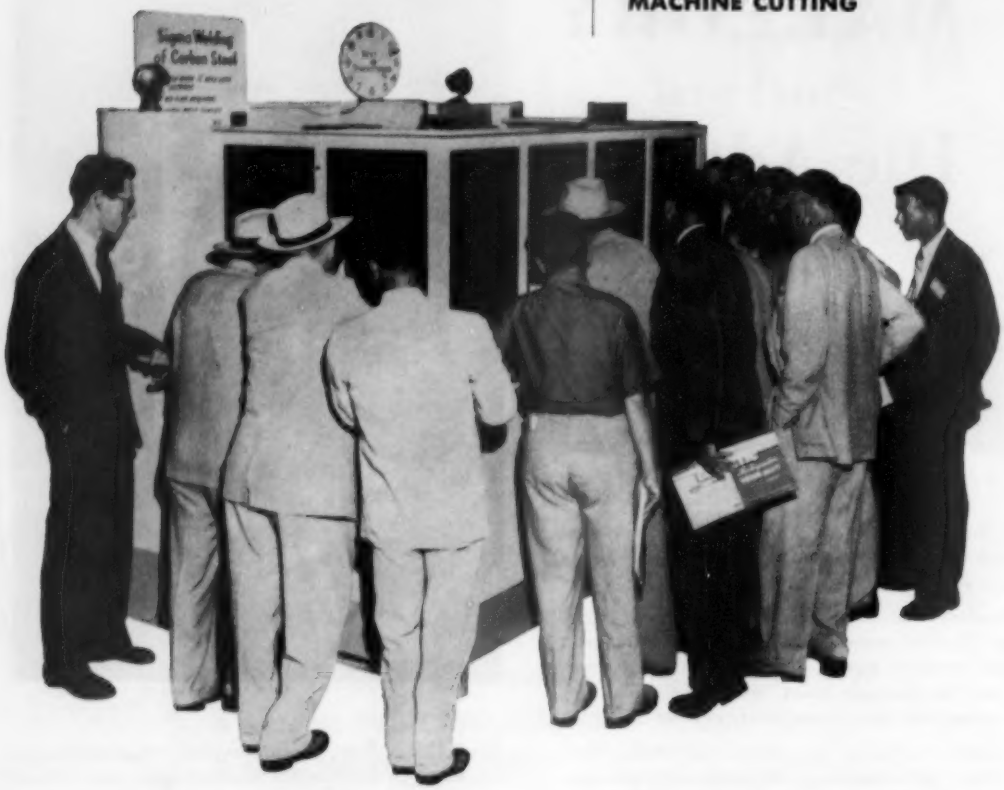

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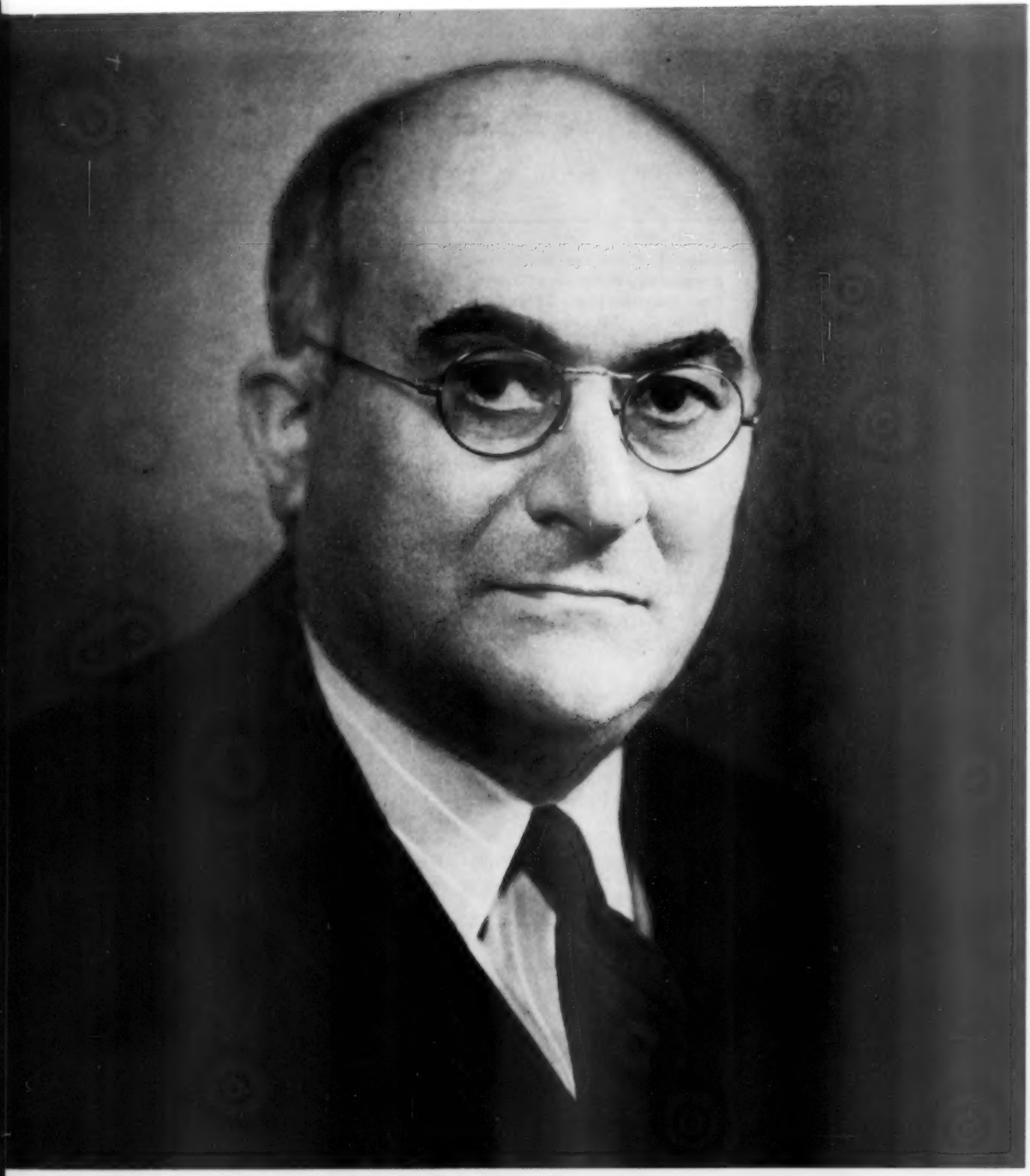

William Spraragen

EDITORIAL

Thank You, Mr. Spraragen!

This issue, Mr. Spraragen, regretfully brings to an end the longest and the most inspiring, beneficial and colorful editorial career in the history of American technical publications—it marks your official retirement from the Editorial Staff of THE WELDING JOURNAL. The literary contribution that you have made to the art and science of welding during the past thirty-three years will never be forgotten; on behalf of the countless number of men of welding, not only in this country but throughout the entire world, who have reaped the benefits of your tireless efforts, we profess to you an infinite debt of gratitude.

Thank you, Mr. Spraragen . . . for your foresight, courage, and steadfast confidence in founding a Journal which, before very long, was destined to spread the welding gospel to all corners of the universe . . . for your unsparing self-sacrifices in time, comfort and, yes, even in health, so that you might secure and maintain for the AMERICAN WELDING SOCIETY the most authoritative publication of its type available anywhere.

Thank you . . . for your constant and unparalleled diligence, conscientiousness, devotion and efficient service to THE WELDING JOURNAL as Editor, Business Manager and Advertising Manager . . . for the broad scientific and technical knowledge, administrative skill and editorial acumen that you have always exercised.

Thank you . . . for your unwavering loyalty to the AMERICAN WELDING SOCIETY and to the industry for which it stands . . . for fostering their prestige, success, and over-all welfare.

THE WELDING JOURNAL of today, Mr. Spraragen, is a fitting monument to your moral strength, sagacity and leadership—it will always stand as a symbol of your pioneering spirit, your deep faith in things of welding and your sincere concern for your fellow man. Thank you, for all you have done, Mr. Spraragen!

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In some applications this simple method may not suffice because evaporation of the TEMPILSTIK° mark on prolonged heating, or its gradual absorption by the surface at high temperatures, may leave too little residual substance for unambiguous observation. In such cases stroking or touching the work-piece with the TEMPILSTIK° at regular intervals during the heating process is recommended. The TEMPILSTIK° will leave a dry mark at temperatures below its rating and a liquid streak when its temperature rating has been reached or exceeded. If the workpiece is not accessible for applying a TEMPILSTIK° during the heating process, then TEMPILAQ°, or possibly TEMPIL° PELLETS, should be used instead.

TEMPILSTIKS° will usually glide over unheated polished surfaces (like glass, polished stainless steel, etc.) without leaving an appreciable mark. Therefore, in applications that involve smooth or polished surfaces TEMPILSTIKS° should be used by touching or stroking the workpiece periodically during the heating process, as previously described, because a liquid streak will be made on contact as soon as the specified temperature is reached. Where it is necessary to mark a smooth work piece surface prior to heating, TEMPILAQ° should be used.

A hot radiating surface will appear relatively dark under intense illumination from an external source, and this fact can be utilized to improve recognition of the temperature signal against a red-hot background. The use of TEMPIL° PELLETS or TEMPILAQ° instead of TEMPILSTIKS° will further improve visibility under these conditions.

On rapidly moving objects, like magnesium or aluminum sheet during spinning operations, it is impossible to see whether the applied TEMPILSTIK° leaves a dry or melted mark. However, with a little experience operators quickly learn to sense the smooth gliding of a TEMPILSTIK° over a surface which is hot enough to melt it on contact, as contrasted to the frictional drag on a cooler surface. If the top of the TEMPILSTIK° is brought in contact with the moving metal surface for a brief moment at a time, and with light pressure only, the heat contribution of friction is trivial enough to be ignored.

The above described "sensing technique" may also be employed on hot radiating surfaces where the bright background makes it difficult to distinguish whether or not the TEMPILSTIK° mark had melted.

An appropriate series of TEMPILSTIK° marks, applied to the workpiece or surface under investigation before heating begins, will provide a record of the maximum temperature attained during a process or operation. Subsequent examination will show that all TEMPILSTIK° marks up to a certain temperature rating had melted, while those of a higher rating had not. The maximum attained temperature must consequently lie somewhere in the interval between the highest melted and the lowest unmelted TEMPILSTIK° rating.

The temperature distribution and isothermal boundaries of surfaces such as furnace walls, melting ladles, cement kilns, etc., can be established by using an appropriately chosen series of TEMPILSTIKS° to draw a pattern of lines (parallel, concentric, radial, etc.) on the area under investigation. The heat conduction along a surface can be effectively studied by the progressive melting of suitably chosen TEMPILSTIK° lines. Caution must be exercised not to permit the mark made with one TEMPILSTIK° rating to cross or overlap the mark of a dissimilar TEMPILSTIK°, as such a mixing of different TEMPILSTIK° marks would destroy their accuracy.

TEMPIL° products will give good results in induction heating and in ionized air, as well as in the presence of static electricity about electrical equipment, where electrical means of measuring temperatures often function erratically.

HARDENABILITY EVALUATION OF WELDING ELECTRODES

Author covers testing procedures and results obtained during investigation designed to evaluate electrode deposits after heat treatment

BY LEO M. WEST

ABSTRACT. In the aircraft industry most weld assemblies involving hardenable steels are heat treated after the welding has been accomplished. In most cases it is desirable, after such thermal treatments, to have the strength of the weld deposit match the strength of the parent material.

This report covers testing procedures and results of many tests for electrode deposit evaluation after heat treatment. It also includes a discussion of the proposed new MIL specification designed to cover this field.

Introduction

As a prelude to the incredible growth of the aircraft industry we should go back a few years to readily observe the progress made in commercial aviation. Figure 1 shows the type of aircraft that was under contract for the first air delivery.

Obviously, when this first delivery flight of approximately 62 miles was made by Diddier Masson on January 3, 1911, consisting of 4 bundles of newspapers, a special edition of the Los Angeles Times covering the Tournament of Roses for that year, little thought was given to thermal treatments of structural parts as a means of increasing the factors of safety against greater loads and faster speeds as time went on. With a roll of bailing wire and a little cloth in one pocket, a pair of pliers in the other, those in Mr. Masson's class were ready and capable of any major repairs.

The "Cloudster" (shown in Fig. 2), built in 1920 was the first aircraft to successfully lift its own weight in payload and a forerunner of the first commercial transport aircraft. Ships of this type were used by Western Air Express, now known as Western Air Lines, the first established passenger airline in the United States.

Fig. 1 First air delivery; distance approximately 62 miles

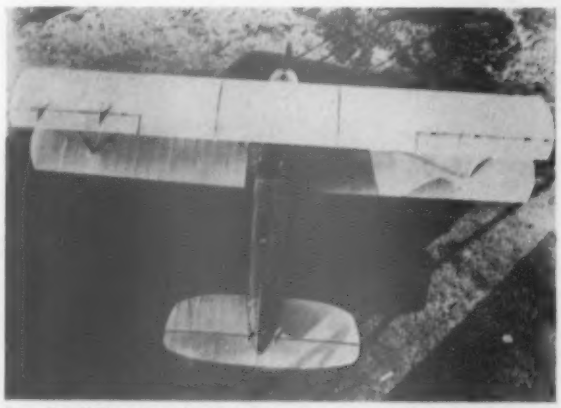


Fig. 2 "Cloudster," first aircraft successfully to lift its own weight in payload

Leo M. West is Materials and Processes Engineer, Douglas Aircraft Co., Inc., Long Beach Division.

Paper is to be presented at the 1955 AWS National Spring Meeting to be held June 7-10, 1955; Kansas City, Mo.

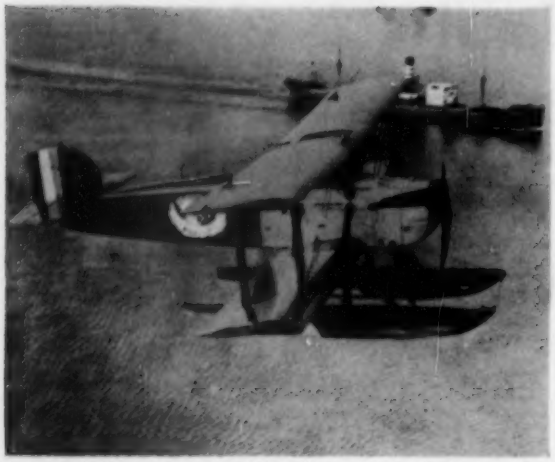


Fig. 3 "Chicago," one of the four planes that were first to fly around the world

This type of craft, as was the "Chicago" (shown in Fig. 3) one of the four planes to fly around the world in 1924, shown here in a trial flight out over the Pacific, were all tubular construction and all welding was done by the oxy-acetylene process. All straightening and such thermal treatments that were required for stress relief, were done with a torch here and there, a bucket of water and a good sized wet rag to quench where and as necessary. Not until approximately 1936 was arc welding accepted as a means of fabrication by the Army Air Force for the aircraft industry. The type of electrode adopted for use was the E6013 series primarily because it laid down nicely, defluxed very readily and the strength factor was sufficient to take care of any type of structure then being built. However, the future seemed to bear down on the industry just a little bit faster than they, the people of the industry, anticipated. Electrodes were developed, specifications were drawn up for Government qualification purposes and procurement of electrodes; also for control of strength factors governing designs. Electrode manufacturers were producing electrodes whereby such thermal treatments as a stress relief after welding would appreciably increase the strength of the structure to required standards. As we went into World War II, the demand became greater for high stressed parts in aircraft. A few heat treatable electrodes were available that would respond to a certain degree of hardness as an admixture in 4130 or 4140 steels when heat treated and drawn at certain temperatures. However, when the heavy transport as shown in Fig. 4, and the high speed jet propelled craft, seen in Fig. 5, began leaving the design boards, far greater strength values were needed than had previously been anticipated and the applicable specifications were becoming obsolete of purpose. Figure 6 shows the struggle to obtain these strength values.

Research Investigation

The dire need for electrodes that would be compatible in response to heat treatments of high strength alloyed steels required in the manufacture of parts and components for the aircraft and rocketry industries resulted in the initiation of an extensive research program.

Prior to 1950, AN-C-5 limited the design strength of welds in tension to 135,000 psi. Even at that time some welding rod manufacturers were producing electrodes which they claimed would have appreciable hardening characteristics when heat treated after welding. There was considerable divergence of opinion, however, concerning what constituted heat treating. One standard practice was to stress relieve after welding at 1150° F for one hour.

While this is a "heat-treat" it is not what is generally meant by this term in aircraft fabrication.

Similarly, some reported data was based on a soaking temperature of 1650° F followed by a quench, sometimes in water, and a conventional draw. This practice also is not typical of the aircraft industry. Re-

Fig. 4 Loading a C-124 heavy transport plane

Fig. 5 Douglas RB 66 in flight

gardless of how the results were obtained, they were sufficiently promising to merit investigation by the aircraft and rocket manufacturers who are always interested in reducing weight. Discussions among several welding engineers of the aircraft and rocket companies disclose that many of them had undertaken testing programs to survey the potentialities of these new electrodes.

The results were so promising that the restrictions of AN-C-5, as then written, seemed unnecessarily severe. Furthermore, the specification for the procurement of electrodes AN-E-9 was grossly inadequate to cover the new product. Committee action was undertaken through the Aircraft Industries Association to correct these conditions. One of the first activities of this committee was to obtain information and compile it in chart form, as evidence to substantiate the need for specification revision.

Figure 7 shows the strength levels obtained about five years ago with the then available electrodes. These data indicate a wide divergence of test results for the same electrode when tested by different companies, as well as a considerable range in strengths for the several different electrodes reported. Enough high strength results were found to indicate that some electrodes, under some conditions, would heat treat satisfactorily. Also, by this information, specification AN-E-9 was shown to be inadequate and immediate action was taken by the committee to draft an AN-E-9 revision to include higher strength electrodes and appropriate qualification tests. This problem was not a simple one.

The commonly used aircraft steels are 4130, 8630, 4140, 8740, 4340 and Hy-Tuf. The heat treats range from 125,000 to 240,000 psi with six steel alloys and five

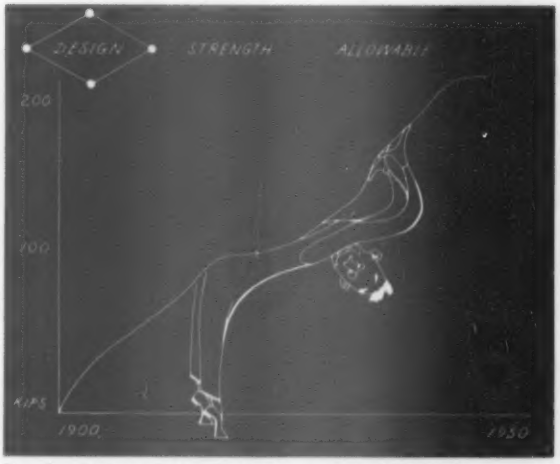


Fig. 6 A struggle to obtain the required strengths

potential strength levels; thirty different test conditions were possible. Multiply this with electrode diameter ranges and the variety of tests which might be required and the total scope of the testing program indicated becomes somewhat overwhelming. In order to reduce this program to a reasonable size, compromises were reached to base the testing on 4130, 4140 and 4340 at the strength levels in which the respective steels are commonly used. These are 125,000, 150,000 and 180,000 psi for 4130. 125,000, 150,000, 180,000 and 200,000 psi for 4140 and 150,000, 180,000 and 200,000 psi for 4340. Figure 8 shows the heat treat procedure used in obtaining these strengths.

In aircraft welding, the preparation of the joint frequently leaves much to be desired regarding the spacing

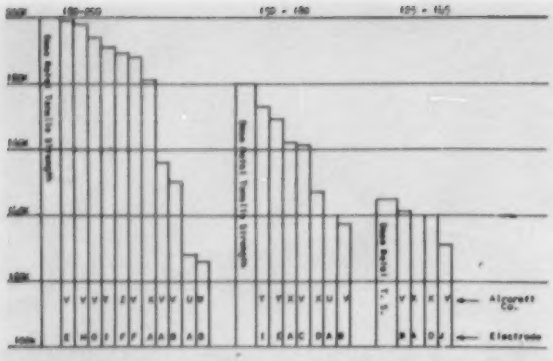


Fig. 7 After heat treatment comparison of base metal and welded butt joints. Tensile strength approximately 1950

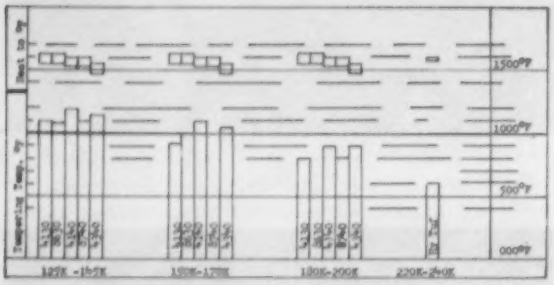


Fig. 8 Heat-treat procedure

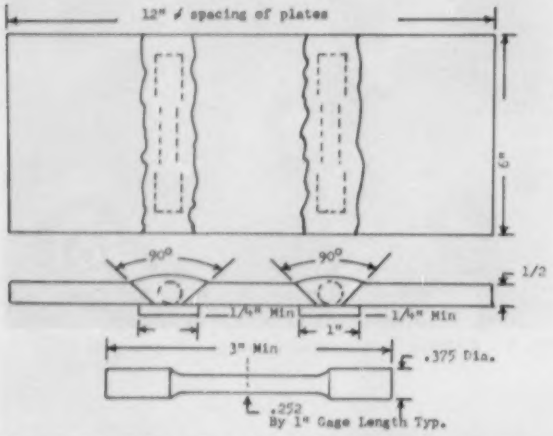


Fig. 9 All-weld-metal mechanical properties test specimen

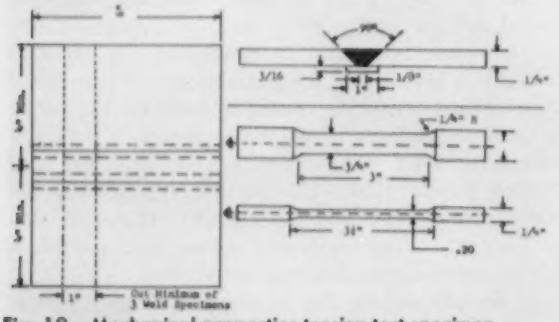


Fig. 10 Mechanical properties tension test specimen

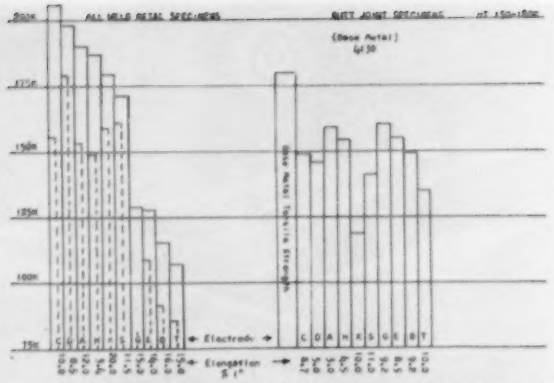


Fig. 11 Tensile test results of all-weld-metal specimens in comparison to butt-joint specimens using 4130 as base metal

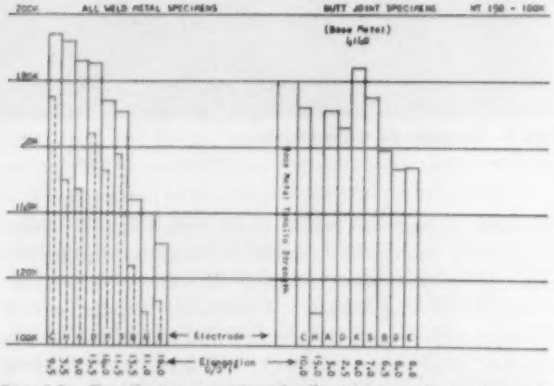


Fig. 12 Tensile test results of all-weld-metal specimens in comparison to butt-joint specimens using 4140 as base metal

of the members. This in turn affects the dilution so that in many instances you may have a transition across the weld from parent material to a diluted band, to "all weld" to a diluted band, and back to parent material. At the Douglas Aircraft Company a testing program was started in which two conditions were studied consisting (a) of all-weld-metal specimens and (b) of butt joints in plate.

In the case of the all-weld-metal specimen, Fig. 9, heat treatment was accomplished before the coupon was machined so that the adverse effect of the steel mass was present during the quenching. This specimen would represent the central portion of a multiple pass weld where very little dilution had occurred. In the case of the butt joint, Fig. 10, heat treating was again accomplished prior to machining. Here the specimen was intended to evaluate any adverse effects of alloying.

In connection with the testing program, various suppliers were contacted. The problem was explained to them and their recommended electrode was tested. Some of these manufacturers were sufficiently interested to go to the expense of new types of electrodes specifically for aircraft use even though they realized that the potential tonnage was small. Others, upon discovering

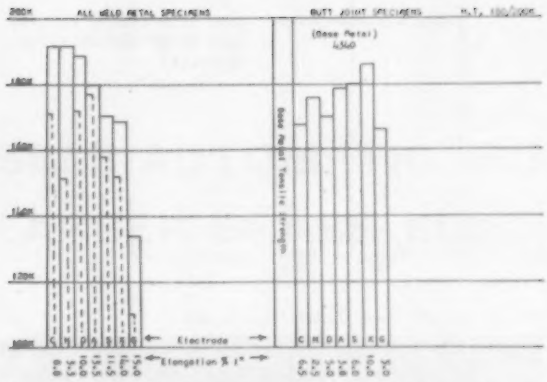


Fig. 13 Tensile test results of all-weld-metal specimens in comparison to butt-joint specimens using 4340 as base metal

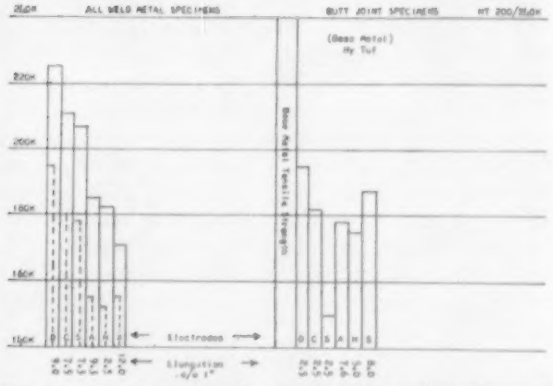


Fig. 14 Tensile test results of all-weld-metal specimens in comparison to butt-joint specimens using Hy-Tuf as base metal

the small probable consumption, ceased to have further interest in the aircraft problem. The results of the Douglas tests indicate a considerable improvement in strength from using electrodes designed to perform in a manner similar to the base metal.

Figure 11 shows the results of the all-weld-metal tests used in making the butt-joint specimens in 4130 steel. In the all-weld-metal specimen the broken lines indicate the yield strengths, while immediately below the elongation is shown. The electrodes are so coded that one may see the comparative results of its use in both the all-weld-metal and butt welded specimens.

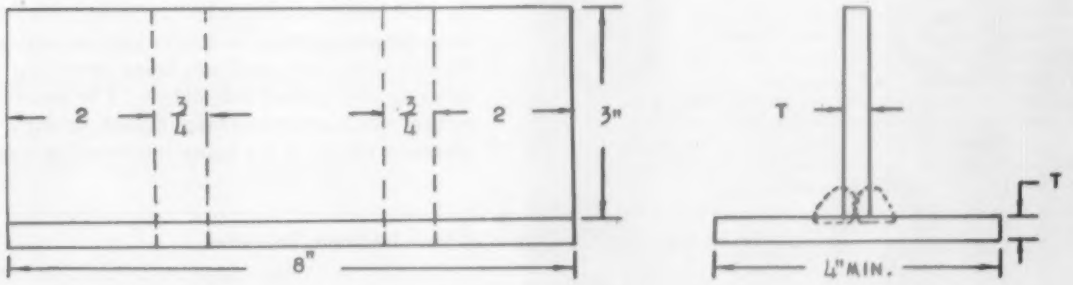
The fact that some of the electrode compositions are more hardenable than the base metal accounts for some of the all-weld-metal specimens having a higher strength than the comparable butt welded specimens at the same draw temperature.

In Figure 12 the strength test results of all-weld specimens in comparison to the butt-joint specimens using 4140 as the base metal are shown. In this case more consistent results were obtained, probably due to two factors, (1) the hardenability of the 4140 is closer to being the same as that of the more hardenable electrode and (2) the 4140 base material seems to have the effect of raising the strengths of the lower hardenability electrodes by dilution.

Figure 13, the base metal being 4340, shows the best results obtained. This can be explained by a continuation of the reasoning of the 4140 test results.

Figure 14 shows the results of tests obtained with electrodes used on Hy-Tuf. Here the comparatively low tensile strengths obtained are not readily explainable. Additional tests are in progress to acquire further knowledge of the reason for the results shown.

Conversely, the tests indicated the danger of possible noncompatible mixtures of base metal and electrode



WHEN VERTICAL WELDING TESTS ARE REQUIRED, WELD SHALL BE MADE UPWARD.

ELECTRODE CLASS	TESTING POSITION	PLATE MATERIAL
E12016 E10013 E10016	VERTICAL AND OVERHEAD	AN-QQ-S-685 OR AN-S-12
ALL HT CLASSES	HORIZONTAL	

ELECTRODE SIZE	THICKNESS T	FILLET WELD SIZE
3/32	1/4	1/8 TO 3/16
1/8	3/8	3/16 TO 1/4
5/32	3/8	1/4 TO 5/16
3/16	1/2	5/16 TO 3/8
1/16" & 5/64"	1/8	1/8 TO 3/32"

Fig. 15 Fillet weld specimen

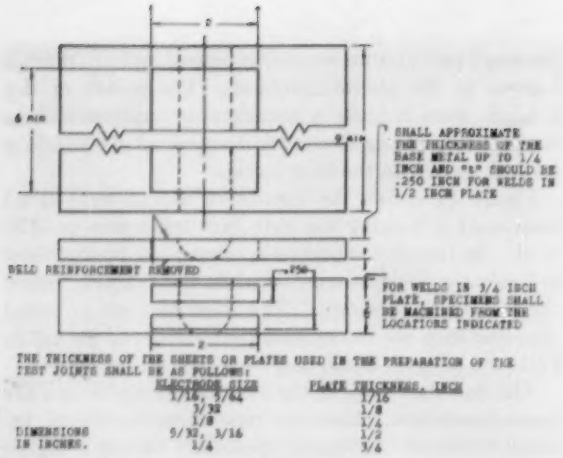

SHALL APPROXIMATE THE THICKNESS OF THE BASE METAL UP TO 1/4 INCH AND "S" SHOULD BE .250 INCH FOR WELDS IN 1/2 INCH PLATE
WELD REINFORCEMENT REMOVED
FOR WELDS IN 3/4 INCH PLATE, SPECIMENS SHALL BE MACHINED FROM THE LOCATIONS INDICATED
THE THICKNESS OF THE SHEETS OR PLATES USED IN THE PREPARATION OF THE TEST JOINTS SHALL BE AS FOLLOWS:
ELECTRODE SIZE
PLATE THICKNESS, INCH
1/16, 5/64
3/32
1/8
5/32, 3/16
1/4
1/16
1/8
1/4
1/2
3/4
DIMENSIONS IN INCHES.

Fig. 16 Bend test specimen

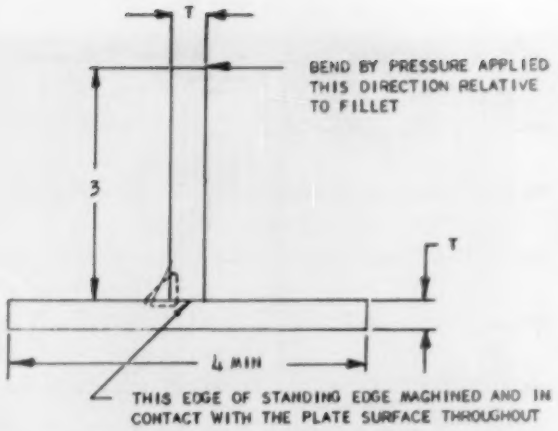

T
BEND BY PRESSURE APPLIED THIS DIRECTION RELATIVE TO FILLET
3
T
4 MIN
THIS EDGE OF STANDING EDGE MACHINED AND IN CONTACT WITH THE PLATE SURFACE THROUGHOUT

Fig. 17 Single fillet weld specimen

deposit and also the possibility of some electrode deposit hardening too much and thus creating machining problems.

The Douglas tests, and similar tests being conducte l by others, resulted in sufficient data being available to convince the writers of the military specifications that reliable hardenable electrodes are commercially available and produce welds having adequate structural integrity. This resulted in a new specification having as its key requirements the items shown in Table 1.

All-weld-metal specimens, like the Douglas specimens, are required: butt joints and plate specimens are required; double fillet joints are required, prepared from electrodes of H. T. classes as shown here in Fig. 15 to be welded in the horizontal position only; this in turn to be sectioned and polished for observance of any weld defects; face and root bends are required as shown in Fig. 16 and impact strength is being considered. Testing will be accomplished at Government Laboratories and electrodes passing will be placed on Qualified Products List. To simplify labeling, a coding system has been prepared as shown in Table 2. For general acceptance tests of electrodes in all classes after having been duly qualified, a single fillet joint such as shown in Fig. 17 shall be bent in direction as shown until weld fractures and the fractured weld examined for any weld defects.

Table 1—Electrode Classification

Code	*Intended use*
E10013 E10015 E10016 E12015 E12016	E-Series electrodes for the production welding of joints in low-alloy steel sheet and tubing which will not receive subsequent HT to develop high mechanical properties
HT125A	Ultimate tensile strengths from 125–145 K.
HT150A	Ultimate tensile strengths from 150–170 K.
HT180A	Ultimate tensile strengths from 180–200 K.
HT125B	Ultimate tensile strengths from 125–145 K.
HT150B	Ultimate tensile strengths from 150–170 K.
HT180B	Ultimate tensile strengths from 180–200 K.
HT150C	Ultimate tensile strengths from 150–170 K.
HT180C	Ultimate tensile strengths from 180–200 K.
HT200C	Ultimate tensile strengths from 200–220 K.

NOTE: Letter A in code designates suitability for use with 8630 and 4130 steels; letter B, for use with 4140 and 8740 steels; and letter C, for use with 4340 steels.

Conclusions

In conclusion, the development of the specification and electrodes has been due to the cooperative effort of both the users and some of the suppliers. The optimum condition, where the weld deposit matches the base metal in mechanical performance over a wide range of heat treatments is still a goal and not a reality. Furthermore, new steels are being developed and the strength level pushed still higher. The result is a fluid picture with progress being gained through the cooperative efforts of the many interested parties.

Table 2—Mechanical Properties of Heat-Treatable Electrodes

		Heat treatment		*Mechanical Properties*			
Electrode class	*Material*	*Oil quench from ° F*	*Temper at ° F**	*Ultimate tensile strength, 1000 psi*	*Minimum yield strength, 1000 psi*	*Elongation % 4 × diam.*	*Elongation for free bend, %†*
HT 125A	4130	1550/1625	1125	125–145	100	11.0	17.0
HT 150A		1550/1625	950	150–170	120	8.0	12.0
HT 180A		1550/1625	875	180–200	145	6.0	10.0
HT 125B	4140	1525/1600	1150	125–145	100	11.0	17.0
HT 150B		1525/1600	1050	150–170	120	8.0	12.0
HT 180B		1525/1600	900	180–200	145	6.0	10.0
HT 150C	4340	1475/1550	1125	150–170	120	8.0	12.0
HT 180C		1475/1550	975	180–200	145	6.0	10.0
HT 200C		1475/1550	850	200–220	160	5.0	10.0

* ± 25° F
† Bend angles should be recorded.

SEMI AUTOMATIC MULTIPLE FLAME BRAZING LARGER BRASS ELECTRONIC COMPONENTS

Operator is engaging the electric switch which controls the timer. Note that the pilot lights are on, and when the switch is thrown, the cycle for brazing will begin

A combustion mixture of oxygen and propane gas found to be most convenient to use with a multiple flame gas burner arrangement to give full brazing penetration

BY J. W. WEYERS

ABSTRACT. Excessive factory rejects on larger brass electronic assemblies were experienced with hand torch brazing. A mechanized method had to be selected to improve quality.

Methods investigated included: induction heating, salt bath brazing, furnace brazing, inert-arc hand welding, inert-gas metal-arc welding and gas burner heating.

The gas burner method was studied to determine variables such as: type of gas to use, combustion mixture, cost of gas, type of burner nozzles, direction and distance of flame impingement, holding fixtures, etc.

After selecting the method to use, the proper brazeable material was specified, as well as joint design and clearance and brazing filler metal.

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Paper is to be presented at the 1955 AWS National Spring Meeting to be held June 7–10, 1955; Kansas City, Mo.

Introduction

The Welding Laboratory of the General Electric Co. in Syracuse was asked to investigate methods other than hand torch brazing for the assembly of rectangular brass tubing (6.500 × 3.250 × 0.080-in. wall) to heavy brass flanges (see Fig. 1). The problem was two fold because the material composition of the flange casting was such that the alloy was considered doubtful for good brazing. Specifications for electrical conduction inside the tubing required that interior dimensions after brazing be ±0.005 in., the flange face to be machined perpendicular to the tubing, and no voids allowable on the flange face, where bolted flange connections were made. Because of these critical tolerances, selecting the proper process was of paramount importance.

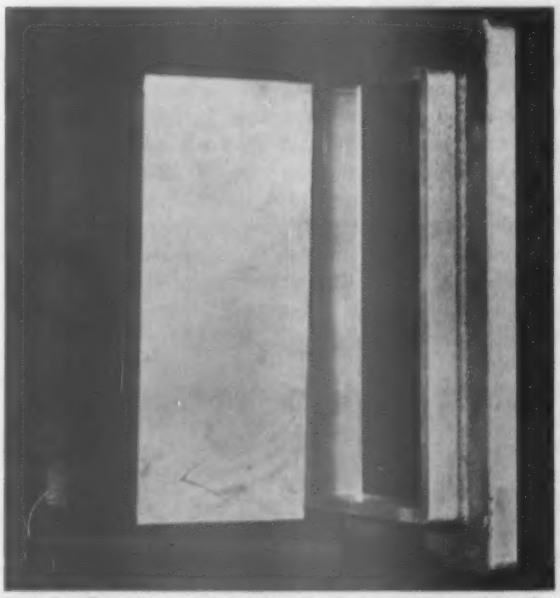


Fig. 1 The rectangular tube is shown prior to insertion into the flange. The tube is assembled so that after brazing, a machining operation on the flange face will leave a square edge and a porosity-free surface

To determine a satisfactory process, methods investigated were:

1. Inert-gas metal-arc welding on back side of joint with soft solder on face
2. Inert-arc hand welding on back side of joint. Same on face
3. Furnace silver alloy brazing
4. Salt bath brazing
5. Induction heating for silver alloy brazing
6. Gas burners with timer cut-off or thermostatic control.

When gas burners appeared likely to be readily adaptable for the operation, the investigation was continued to determine type of combustion mixture, type of burner tips to use, burner spacing, angle of flame impingement, distance of burner tips from joint, type of holding fixture necessary, type of temperature control, volumes of gas for best results, joint clearances and design, type of alloy, method of feeding alloy and sequence of brazing and machining operations.

Procedure

Factory complaints of cracked flanges had been received regarding the 85-5-5-5 castings. By Laboratory experimentation of differential heating and cooling with a hand torch, it was relatively simple to start crack propagation. Chemical analysis showed that the casting material conformed to the specification. Macro examination showed surface defects which could easily start crack propagation under slight stress. Also, since these flange castings were machined before brazing, stress points were available at all drilled holes. We were continually plagued with the question of clearance and tolerance of the parts in this first experimentation with the flange material as well as throughout the entire investigation.

The decision was made to go to a forged, broached, undrilled flange to alleviate difficulties mentioned above. A forging would eliminate the surface imperfections which could cause cracks; also would eliminate the stressed areas of the drilled holes while brazing. The 60 Cu, 38 Sn, 2 Pb forging was also extremely plastic in the brazing temperature range, making a fairly flexible consideration possible regarding clearances, tolerances and differences in expansion coefficients. Outside sources of information indicated that forgings in all cases were preferable to cast flanges for brazing or welding.

Inert-gas metal-arc welding the backside joint with soft solder on face was investigated as presumably being the most economical method of fabrication. The welded joint showed promise of acceptability and was completed in about one minute. An aluminum bronze filler metal was used. The joint failed to pass the close dimensional tolerance due to excessive warpage and distortion from the intense heat of welding. Solder flux was entrapped in the joint prohibiting a porosity free surface on the face of the flange as well as causing the possibility of corrosion origination.

Inert arc welding (with the tungsten electrode) was also investigated with the weld made on both face and backside of flange. Distortion here also was considerable.

At this point, it was decided that welding experiments be dropped, and brazing methods should be examined. If brazing should not prove satisfactory, methods of welding would be continued in an effort to control warpage and distortion.

Furnace Brazing. Samples were prepared and processed through an electric furnace. Unsatisfactory results were achieved because a flange must be brazed to each end of the tube. Therefore, a locating fixture problem existed. Also, the preplacing of the alloy for uniformity of brazed joints was an almost impossible problem to solve. Another disadvantage was that the brazing alloy melted before the base metal came up to temperature. Slower heating time to prevent early melting of the alloy would be prohibitive costwise. Also, furnace brazing is applicable only where capillary attraction can be utilized. On some of the joints, the clearance is as high as 0.024 in. and the joint is completed largely by gravity only.

Salt Bath Brazing. The assemblies were prepared by hand filing a chamfer on the top edge of each flange cleaning all surfaces by emery or steel wool, fluxing and then assembling with the 51 Ag, 15 Cu, 16 Zn and 18 Cd alloy and brazing as follows:

1. Assembled with two $^1/_{16}$ in. diameter wires and selectively immersed in the bath for a preheat of 3 min. Only a portion of the flange was immersed.
2. Full immersion for brazing at 1350° F for three minutes.
3. Air cool to room temperature.
4. Hot water washed, rinsed and dried.

Results and Comments. Due to the variance in joint tolerances, either a closer control over dimensions must be maintained or a more viscous silver solder must be used in order to completely fillet all joints.

Next, a more viscous alloy (50 Ag, 15 Cu, 16 Zn, 16 Cd, 3 Nu) was tried with varying results depending on joint clearance. Here again, as in furnace brazing, clearance must be such that capillary attraction can be utilized because large clearances up to 0.024 in. allowed alloy to flow through the joint and into the bottom of the salt pot. Unlike in furnace brazing, premature melting of the alloy was avoided by preheating the flange. Also, no fixturing problem was encountered, since one flange at a time could be brazed. Operator discomfort due to extremely hot working area around the salt pot was a factor in deciding to explore other methods of brazing. However, salt bath brazing showed promise and no doubt there are many brazing applications where it would be superior to other methods. The difficulty of obtaining the use of the salt bath furnace necessitated experimentations with other brazing processes.

Brazing by Induction Heating

Preliminary investigation showed that three problems existed: how to design an adequate coil, what size

machine to use and the joint design required. A method must be determined on each job as to which techniques and fixturing would be applicable. In most brazed joints, a clearance of 0.001 to 0.006 max is allowed between surfaces to be brazed together. This clearance facilitates the assembly of parts and promotes the capillary attraction of the braze material. The induction coils used are round, oval and rectangular copper tubing or solid bar stock. In each case, these coils are water cooled either internally or externally. Some coils can be encased in a heat resistant cement. The hardened cement can be recessed, grooved, etc. to position the individual parts during the brazing operation. This feature eliminates the necessity of expensive metal fixtures for some applications. On large assemblies having two or more parts of different materials and thicknesses such as we had, the coil or coils must be designed to induce heat simultaneously in all parts. Conduction from one part to another for heat transfer could not be used.

Present equipment for induction heating is limited to 20 kw output which is on the borderline as to being adequate for the job. A few samples were tried and did not meet quality standards but clearly indicated that this method is practical. Work was temporarily discontinued on induction brazing because the equipment did not seem to be of sufficient capacity, the coil design appeared to be an expensive and time consuming job, and the joint design allowed too much clearance for high quality work.

Gas Burners with Timing Control of Flames

Samples were taken to a well-known manufacturer of automatic brazing and heat processing equipment who advised that an automatic machine could be built to accommodate a large percentage of the assemblies to be brazed. This equipment could be purchased for approximately $10,000. Arrangements for the rental of a combustion controller could be worked out which would enable the equipment to be fired by a combination of manufactured gas and atmospheric air. This fuel would make a substantial dollar savings over our present type of fuel. This proposed equipment would offer the following advantages: (1) uniform heat, (2) less distortion, (3) better brazed joints of consistent quality, (4) lower cost.

The report on the results of the samples stated that, "in an attempt to eliminate the bowing (which was attributed to the differential expansion between the extruded copper tubing and the lesser expanding bronze flange), the clearance between the tube and the flange was increased. The clearance on the long dimension was approximately 0.015 in. and on the short dimension was approximately 0.005 to 0.008 in. Two rectangular rings of alloy were preplaced on the joint. The total heating time was 1 min and 50 sec. The burners were throttled down when the preplaced alloy began to flow. The results of this test showed a definite improvement with respect to the bowing of the tube, and there was 100% fillet between the end of the tube and the flange.

"These tests have definitely shown that the entire flange can be heated and brazed in 2 min, and that proper fitting assemblies can be satisfactorily handled with gas radiant heat to produce 100% satisfactory results. Further tests should be conducted to determine the optimum joint design in so far as cold clearance is concerned."

From the results of this study, it was decided to actively pursue the gas burner brazing method. Surplus machinery could be altered for use, eliminating the need for buying the standard brazing equipment.

The object was to set up a universal unit that could be used for the electronic component type of brazing applications.

Required features:

1. It must have a turntable to revolve circular work.
2. The table top must be free of permanent obstructions so that burners can be located at any angle and position on the table for brazing odd shapes.
3. It is advisable to restrict anything from protruding on any side, allowing free workability from all four sides.
4. Automatic cycling is required; that is, push button start and stop and timer cycling for the different stages.
5. Stop button required to stop cycle at any time.
6. At least two different intensities of flame are needed. They must be able to go on and off at any preset time. It may be necessary to have a low preheat, followed by a driving higher flame and then drop into a holding flame to keep parts at a constant temperature. All or any part of this type of cycle must be delivered by the controls.
7. A pilot light for starting is required.

Additional features which may be desirable:

1. Manual control to allow throwing in or out either the high or low flame in addition to automatic cycling.
2. Thermal switch to control cycling to maintain a temperature range.
3. Tilting of the rotating member may be advantageous for some applications.

A surplus machine was purchased and rebuilt (see Figs. 2 and 3). The machine salvaged consisted of a table approximately 3 ft square with a rotating spindle in the center driven by a small 110 volt constant speed motor. Also, a special timer with 5 stations was salvaged along with tee and venturi mixers.

Much consideration was given to the gas combination that would be used. The most economical combination is natural or manufactured gas and air (see Fig. 4). However, this would require a special mixer which would run the initial cost above the present consideration for the job. It is probable that such a mixer would pay for itself in a short time. The other gas combinations considered were acetylene and oxygen, propane and oxygen and natural gas and oxygen. Since natural gas was not in the present factory, this combination was eliminated. Oxy-acetylene combination was

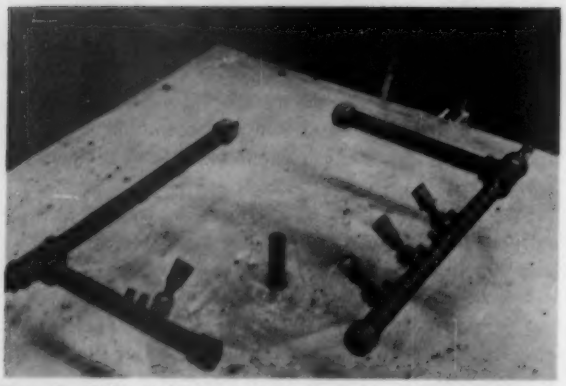


Fig. 2 Fishtail burner spacing and arrangement with holding fixture removed. Note the spindle in the center for attaching a table-top for rotation. Assemblies of a circular nature could be brazed using the turntable

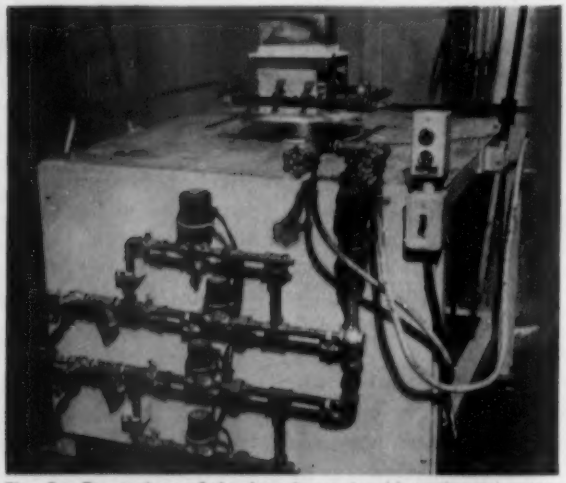


Fig. 3 Front view of the brazing unit. Note the solenoid-pressure control valves, the venturi and mixing chamber and the electric start-stop switch. The mixed gas goes from the mixer, through fireproof hose, to the fishtail burner assembly on the table top

expensive and difficult to handle on an automatic machine. The advantage of a concentrated flame with high local heat transfer which acetylene produces was not desired for this application. Therefore, it was decided to work with the combination of propane and oxygen.

To produce two different rates of flow of each gas at a given cycle required two parallel solenoid valves for each gas. One of the propane solenoids was a pilot solenoid valve. This provided a pilot flame of any intensity desired. The solenoids all operated through the timer to open and close at any preset point during a maximum of 10-min cycles.

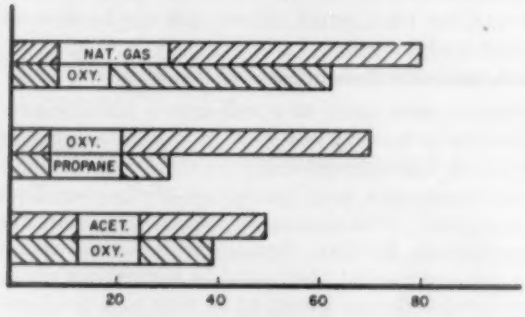
The gases are metered by four needle valves just prior to the solenoid valves. The gases then go to a standard tee mixer and through the venturi mixer. From the mixer, the gases are divided into two lines going to manifolds with four burner tips on each manifold.

The burners used were A.G.F. No. 322 Fishtail tips with $^1/_8$ in. N.P.T. male connection. Three burners were used on each side and one on each end as shown in Fig. 2. This burner arrangement gave a very uniform heat on the parts. The burners were approximately three inches from the work and directed at a 45-deg angle with the face of the flange. The flame impinges near the outer edge of the flange.

The single stage oxygen regulator allowed the pressure to build up during the off cycle, producing an excess of oxygen when the next cycle was initiated. Since this had detrimental results, the regulators were replaced with two stage regulators which held the pressure constant.

To facilitate accurate control on the gas combination and intensity of the flame, flow meters are required for both gases. Thus, suitable gas flow meters were incorporated in the system.

Figure 3 shows the general arrangement of the components. The gases flow through the flow meter into the metering piping at the left side of the photograph. The propane went through the two upper solenoids and the oxygen through the lower valves. The top propane solenoid valve is a pilot valve allowing a small amount of gas to flow to the tips for a pilot. The gases



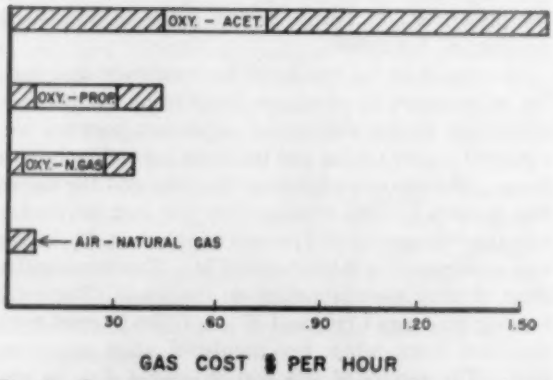


Fig. 4 Comparative gas costs show that the natural gas and air combination is most economical. For similar heat capacity, the acetylene and oxygen combination showed the least cubic feet per hour gas consumption

go through the tee and venturi mixers and are then split and run to the two manifolds. With the four solenoid arrangements, two different intensities of flame may be produced. The control switches are all located on one corner at right of photograph. The timer and rotating motor and reduction are located under the table.

Brazing Unit Operation

A. Set two stage oxygen regulator and propane regulator at 12 psi.

B. Light pilot

1. Open gate valves for propane and oxygen. Wait 10 sec and then light burners.
2. The intensity of pilot flame may be adjusted with valve stem on bottom of pilot solenoid.

Caution: Do not allow gate valve for propane to remain open when pilot is not lit.

C. Five stage timer

1. First stage controls timer on and off.
   Second stage controls upper propane solenoid on and off.
   Third stage controls lower propane solenoid on and off.
   Fourth stage controls upper oxygen solenoid on and off.
   Fifth stage controls lower oxygen solenoid on and off.
2. The on and off of any solenoid can be set at any desired position from immediately as the time is started to 10 min in time.
   (a) It is necessary to have either:
      (i) Propane and oxygen solenoid open at same time or
      (ii) Propane open before oxygen.
      (iii) Propane and oxygen solenoids close at the same time or
      (iv) Oxygen close before propane.
   (b) The timer is now set so
      (i) Upper propane and oxygen solenoids open immediately upon pressing start button, producing low flame.
      (ii) High flame comes on a short time later with lower propane solenoid opening just previous to the lower oxygen solenoid.
      (iii) High flame goes off at approximately $4^1/_2$ min by lower oxygen solenoid closing just previous to lower propane solenoid valve.
      (iv) Low flame will continue until shut off by stop button or until timer shuts off.
3. The lower propane and oxygen solenoids may be closed or opened at any desirable time during its preset cycle by an auxiliary switch.
   (a) This switch was incorporated to prevent overheating.
   (b) It allows manual control over the results of the surrounding variables such as cold baffles, breezes, etc.

D. Steps for adjusting flames

1. Initial setup
   (a) Close lower propane needle valve and both oxygen needle valves
   (b) Light pilot per above
   (c) Initiate cycle
   (d) Open upper propane needle valve to desired propane-flow for low heat (approx. 25 on flow meter).
   (e) Open upper oxygen needle valve to produce neutral flame (approx. balance flow levels on flow meter).
   (f) Open lower propane needle valve to desired flow for high heat (approx. 45 on flow meter for short elbow section).
   (g) Open lower oxygen needle valve to produce neutral flame (approx. balance readings on flow meter).
2. Changing flames
   (a) High flame too high
      (i) Close lower oxygen needle valve to desired flow meter reading.
      (ii) Close lower propane needle valve to produce neutral flame (approx. balance flow meter readings).

Caution: Oxygen must be decreased first to prevent blow back.

      (iii) By changing high flame in this manner, lower flame will not be altered.
      (iv) Lower flowmeter reading may also be produced by lowering regulator pressures, however, when this procedure is followed, both high and low flames are altered.
   (b) Low soaking flame too low
      (i) Open upper propane needle valve the desired amount.
      (ii) Open upper oxygen needle valve to produce the neutral flame.

Caution: Propane must be increased before oxygen to prevent blow back.

      (iii) High flame will have to be readjusted whenever low flame has been altered.

Note: Whenever increasing flame, always increase propane before oxygen.
When decreasing the heat, decrease oxygen before decreasing propane.

E. Rotation

1. The throw switch just below the start-stop push button station, turns the motor on and off.
2. The rotation is not presently tied in with the timer.

With propane and oxygen gas combination and the timer control, it became possible to braze the tubing to the flange. A uniform heat was produced in the parts and the heat was applied in the proper location to flow the braze material in the desired direction.

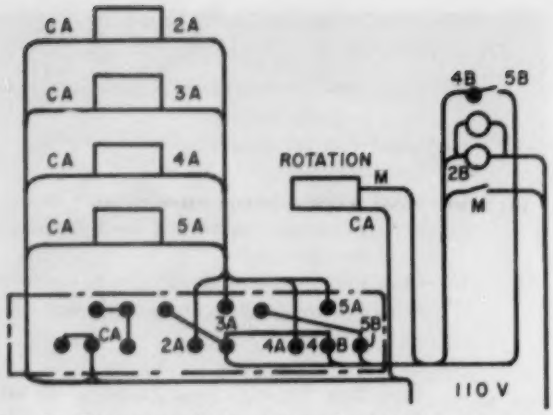


Fig. 5 This wiring diagram shows the interconnections between the times terminal board, the four solenoid valves, switches and rotation motor. Push buttons are used to start and stop the cycle. A toggle switch is used to manually change from one intensity of flame to the other during the cycle. A separate throw switch controls the rotation motor

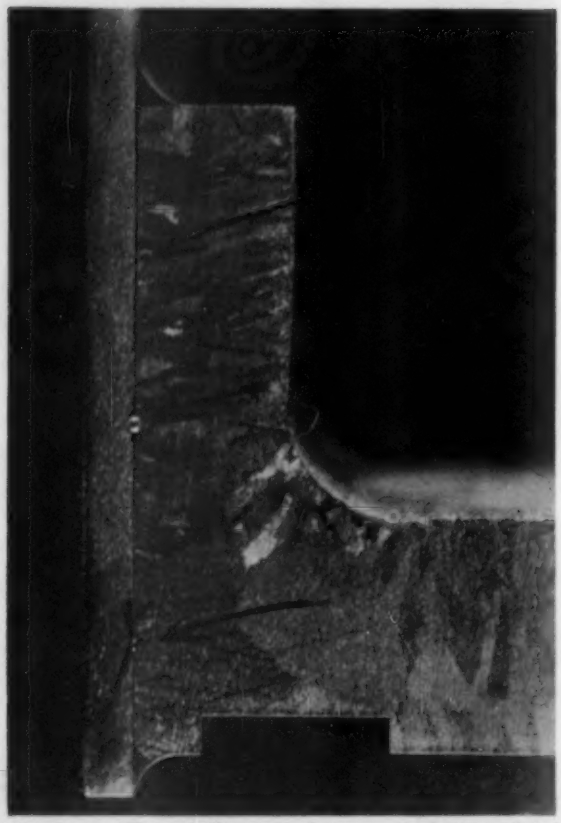


Fig. 6 A 5X magnification of the cross section of the brazed joint showed that porosity was present on the interior of the joint although top and bottom surfaces had excellent fusion

The equipment meets all of the requirements requested. Also, the manual control of both high and low flames was incorporated, as is shown by the wiring diagram (Fig. 5).

Any type and shape of manifold may be used on the apparatus.

Selection of Alloy

After selecting the gas burner process, the next consideration was the type of brazing alloy. A study was made of the following:

Alloy No.	*Silver, %*	*Copper, %*	*Zn, %*	*Cd, %*
1	65	20	15	..
2	51	15½	15½	18
3	45	15	16	24
4	45	30	25	..

The joint design at this time was such that the alloy had to flow 1½ in. through the joint and completely fill the clearance between the parts to be brazed. Since this would indicate a free flowing alloy, we tried Alloy No. 1. It was found to be so fluid with some of the pieces that it would not stay in the joint. Alloy No. 2 was not fluid enough, but Alloy No. 3 seemed to have the right fluidity. Upon further testing of Alloy No. 3, we found that when slightly overheated, which was likely to occur with the open flame impinging on the materials, the cadmium volatilized in the joint leaving pinholes. The last alloy tried, Alloy No. 4, was cadmium free and gave the best results as far as having a sound brazed joint; the disadvantage was that the melting and flowing point is 1250–1370° F or about 15% higher than some of the other alloys. Preplacement of the alloy was considered and the decision made to use a 3/32 square preformed filler to complete the operation so that hand feeding could be kept to a minimum.

Joint Design

On preliminary examination of the joint, it would appear that an attempt to draw the alloy through the 1½ in. thickness of the flange is extremely difficult to do consistently and does not conform to good brazing practices (Fig. 6).

To aid the alloy in penetrating the 1½ in. joint, it was suggested to drill holes in the flange shoulder perpendicular to the brazed joint through which the brazing alloy could be fed to prove that better penetration could be obtained if the alloy has less distance to travel (see Fig. 7, bottom). The results showed good penetration, but the appearance of the exterior of the workpiece was objectionable.

Silver plating both parts prior to brazing was the next investigation. Good penetration was obtained, but the quality was not measurably improved so that there was an advantage costwise.

A reappraisal of the problem of penetration suggested that joints be made up with the flange shoulder removed (Fig. 7, top), necessitating the alloy to penetrate only ½ in. Strength tests were made to find if weakening of the overall assembly would be experienced. In all tests, the tubing failed before the flanges. However, design change approval was not forthcoming, and this phase of the investigation was dropped. A chamfer on the flange face of ⅛ in. depth on a 45° angle was then suggested. In all samples made, none was satisfactory since the brazing alloy would not puddle in and give a

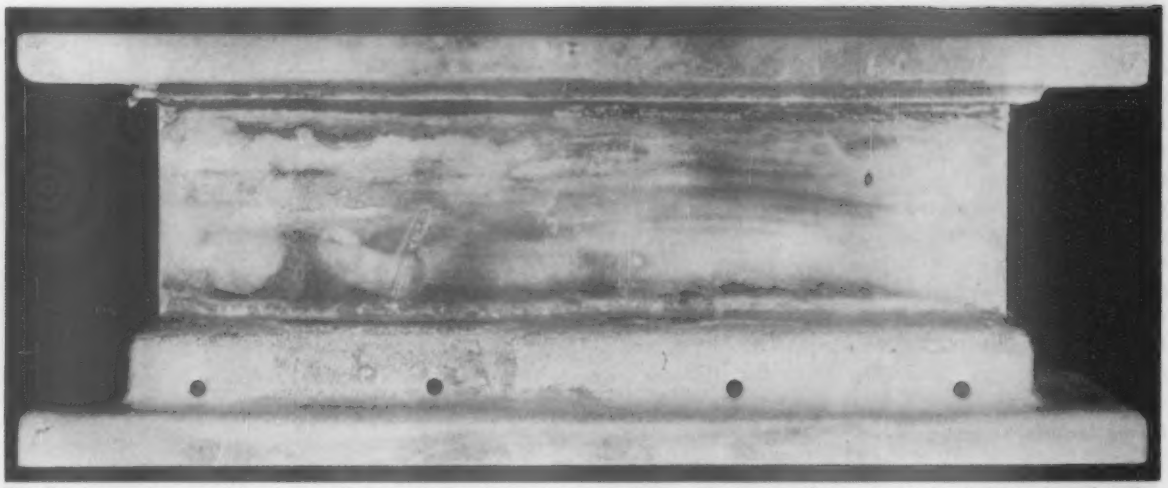


Fig. 7 A sample assembly of two different flanges brazed to the tubing. The bottom flange has holes drilled where brazing filler alloy was added. The top flange has the shoulder removed so that the length of joint is reduced to $^1/_2$ in. for easier brazing as well as for a more solid joint

solid solution of metal in the groove. Surface examination after machining showed pinholes and porosity in the braze (Fig. 8). Figure 9 shows a self-locating flange joint which was unacceptable electrically on the interior of the joint.

Joint Clearance

Clearance for good brazing results presented the most challenging problem. Recommendations from brazing alloy manufacturers were for a clearance of from 0.003 to 0.006 in. Induction heating specialists recommended almost a force fit. In this case, a force fit is not possible due to the geometry of the pieces. A rectangular tube will bow in at the sides if there is interference, and brazing is then impossible. Gas heating specialists recommended 0.015 to 0.020 clearance to compensate for differential expansion rates. Machining tolerances on the flange, and extruding tolerances on the tube, as well as distortion and buckling of the tubing also had to

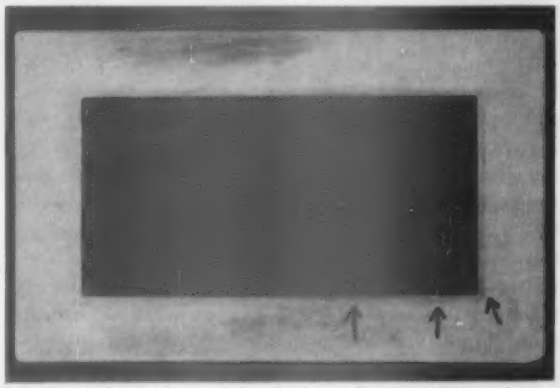
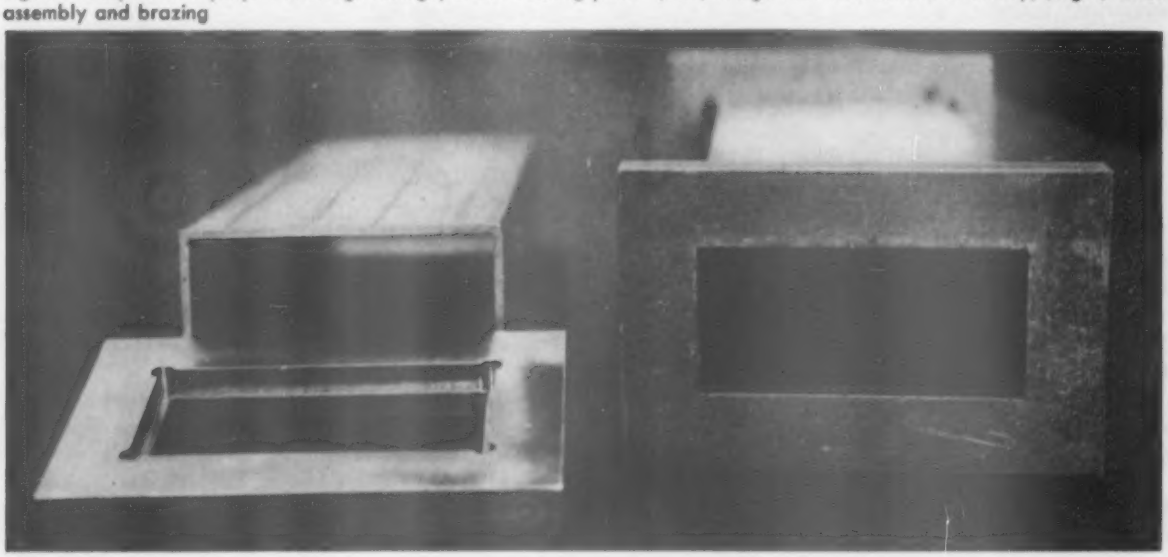


Fig. 8 A face view of the flange after brazing and machining. Objectionable pinholes appear after the brazed surface is machined

Fig. 9 Samples of a proposed design change, a self-locating joint. *(Left)* flange and tube before assembly; *(Right)* after assembly and brazing



be considered when investigating joint clearances. During the cut-off-to-length operation on the tubing, enough distortion or bending was experienced to necessitate a straightening operation. Mill tolerance on the tubing was ±0.005 in., and machining tolerance of the broached rectangular hole was ±0.002 in. Using the optimum clearance as recommended by the alloy manufacturers, results were a total possible clearance of 0.009 to 0.023 or 0.0045 to 0.0125 on a side. This eliminated an expensive hand selective fitting operation although it interfered with the program to set the operation up as automatic, since a close clearance heated up faster with less heat than a loose fit. Since time and amount of heat varies with clearance, automatic cycling could not be utilized.

Flange Material Selection

Up to this time, factory schedules had to be met with existing materials until a more desirable flange material could be selected and also to utilize materials already on hand. The cast flanges were given good flux coverage, but we experienced distillation and oxidation of zinc as well as formation of lead drosses and subsequent embrittlement of the brazing alloy. Examination under magnification showed surface defects which could propagate the stress cracking that was prevalent in the castings. As a result of recommendations of brass manufacturers and the trouble experienced with the castings, the material of the flange was changed to 60 Cu, 38 Zn and 2 Pb forging brass. The disadvantage associated with this material is the extremely weak composition at brazing temperature. The rubbery, plastic nature of the forging at high heats necessitated more supporting fixtures to hold dimensions.

Plumbing recommendations for piping in propane gas to the installation:

The use of ASTM A106 steel piping was recommended. Based on a gas consumption of 50 cfh at 10 lb gage pressure and an estimated pipe run of 40 feet, $^1/_2$-in. pipe is acceptable. However, due to the nature of the work, it might be desirable to increase gas consumption; therefore, a minimum pipe size of $^3/_4$ in. is recommended. Pressure drop in the $^3/_4$-in. pipe for the above conditions is 0.005 lb-ft of length.

The pipe may be assembled by means of threaded connections.

Caution: Propane has a solvent action and will dissolve most pipe thread dope. Plumbing people recommend a on-soluble pipe thread dope.

For a permanent installation, it was recommended that the joints be welded by a qualified welder who has been certified to weld steel piping in all positions.

If liquid propane is to be used, then only welded pipe joints should be used. The steel pipe must be clean and free from rust and scale. Propane gas will loosen scale.

While copper tubing might be used, it is not recommended. Likewise, flared soldered or brazed fitting is not recommended.

Propane is a heavy gas having approximately $1^1/_2$ times the density of air and $2^1/_2$ times the heat value of natural gas. Being heavy, it will settle and not be dissipated into the surrounding atmosphere like some of the gases. It is very potent, and no appreciable quantity should be released without burning it during any setup or operation.

Conclusions

The gas burner brazing unit was turned over to the factory. This was after satisfactory results were obtained from brazing 98 flanges onto 49 sets of parts. Examination of the parts with inspection showed no pinholes, porosity or voids after final machining of flange faces.

These results were obtained with:

1. Forged flanges located flush with end of tubing.
2. $^1/_{32}$-in. chamfer on face and backside of flange prior to brazing.
3. Clearances per present drawing dimensions maximum 0.024 and minimum 0.009. Note that commercial tubing sometimes does not meet drawing dimensions and occasionally flanges do not fall within tolerances. Needless to say, for excessively loose or tight fits, acceptability percentage will be below that experienced above.
4. Gas volumes were 54 cfh on the high preheat flame and cut down to 31 cfh when brazing alloy flows. Tip angles to be adjusted so that tubes are heated evenly and uniformly.
5. Two operators feeding alloy by hand were able to obtain good quality, fast joints, with an approximate production rate of 20 brazed flanges per day.

The original intention was to set up an automatic process, but the variables could not be adequately controlled. The operators must still use considerable discretion.

General Comments

This brazing equipment is generally adaptable to other components due to its flexibility and changeover to other setups is simple. On round tube to flange joints, the part to be brazed is rotated and flame distance is not critical.

On rectangular tubes, flame distance and distribution of heat must be accurately controlled by proper location. Otherwise, uneven heating results with the hottest point getting up to brazing temperature first. This causes the alloy to fill up unevenly and excess braze runs through the joint pushing the tube away from the flange at that point. The clearance then is all on the one side and is difficult to fill up.

Open flames must be kept away from direct contact with the molten brazing alloy if possible. This avoids overheating and volatilization of zinc which in turn results in pinholes under the top layer of solid deposited braze.

Other brazing or welding methods no doubt would have been found satisfactory if sufficient time and money had been available for investigation.

The multiple flame burner method was acceptable since quality was entirely adequate with minimum costs for machining and brazing.

Fig. 1 Set up for manual nonconsumable-electrode inert-gas welding

FUSION WELDING UNALLOYED TITANIUM SHEET WITHOUT FILLER ROD

Entirely acceptable welds can be produced in titanium sheet metal for the most severe service by using the latest techniques, with the addition of filler rod and especially without filler rod

BY ALAN V. LEVY AND ROBERT WICKHAM

SYNOPSIS: The great fluidity of titanium metal in the molten condition lends itself to fusion welding without the addition of filler metal. The resulting welds are flush with the base metal and have high ductility, comparable to the ductility of the base metal. The welded joints can be made by hand or automatic methods. A critical requirement of this type of weld is fitup of the parts to be joined. The backup and holddown fixtures also have a decided effect on the resulting weld. A sheared surface resulting in a no-gap joint is required for a satisfactory weld. Fused welds have been principally used, to date, for longitudinal tight butt joints in material up to 0.060 in. thick. Further testing and experience should extend the limits of application. Bend tests made on welded samples have bent 180° over a 2T bend radius exhibiting equal or greater ductility than the base metal. Welds tested in tension have exhibited over 100% efficiency in all cases. The elimination of welding rod has reduced the amount of contamination in the weld and the weld area.

Introduction

Considerable effort has been expanded during the past few years to develop satisfactory techniques for fusion

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welding commercially pure titanium sheet metal. The technique of using the nonconsumable-electrode method of welding in a complete inert atmosphere surrounding the weld joint has become somewhat standard procedure. The use of filler rod stripped from the base metal has also been used extensively. In order to reduce the amount of weld bead grinding required to produce certain critical parts for turbojet and ramjet engines, the Material & Process Laboratory at Marquardt Aircraft Co. has investigated the manual welding of titanium sheet without the addition of filler metal. The results of this investigation showed that the complete character of the resultant joint was improved by welding the material without rod.

The problems connected with grinding titanium weld beads primarily centered around the severe grinding wheel wear associated with the operation and the time necessary to remove a given volume of metal. In addition, a tendency to overheat the metal at the joint resulted in localized embrittlement of the weld. The involved procedure required to remove the embrittled area and rework the part proved to be uneconomical, at best, and resulted in scrapping of the part in a few severe cases. The danger of embrittlement due to overheating during grinding operations was evidenced in one case by a sudden failure during a subsequent spinning operation. Eliminating the grinding operation considerably improved the quality of titanium parts.

Initial Experiments

Initial experiments used the same general hand welding conditions as had been previously used for welding with the addition of filler rod. These conditions will be discussed later.

The material welded was 0.040 in. MST Gr. III commercially pure titanium in the annealed and pickled condition. The joint edges were sheared and tightly butted together with no gap.

The results of these tests were significant. They established the fact that major gains in desirable weld configuration and ductility were possible by welding without rod. Refinement of the welding conditions improved the joint characteristics further. However, the first series of flush welds made exhibited the major improvement in ductility over welds made with filler rod under similar conditions.

The resultant welds were flush on the top surface and slightly concave on the underside. There was no dropping or undercutting of the weld nugget as commonly occurs when steel is welded without filler rod. The weld metal color was silvery in appearance, indicating a minimum of contamination from the air. A dark blue scale color area ran along each side of the weld in the base metal. This band was approximately $^1/_8$ in. from the edge of the weld bead.

Bend tests were made parallel to the weld and tensile tests made across the weld. A comparison was made with the properties of joints welded with added filler metal. A decided improvement in bend ductility had been realized with little loss of tensile strength. The weld joints approached the ductility of the base metal while the joint efficiency remained above 100%.

A more detailed investigation of the phenomenon was a logical outgrowth of the original tests. Efforts were made to document the increased ductility and to further investigate the effects of the welding variables on the strength and ductility of the joints. In addition, experimental parts were welded to determine the feasibility of the process on actual parts where obtaining the tight fit-up necessary to make a reliable weld could be a problem.

The major improvement realized by welding without the addition of filler rod can be explained readily. The loss of ductility in the weld joint is due, in part, to the absorption of gases such as oxygen, hydrogen and nitrogen into the weld metal from the air. These gases become interstitial alloying elements that decrease the ductility of the resulting joint. The use of filler rod extends a path for the air to penetrate the argon blanket around the weld puddle and contaminate the weld. Eliminating the rod enables the blanket to remain unbroken and it more effectively protects the molten surface of the metal. The reduction in contamination from the surrounding atmosphere is the principal cause for improvement in the weld ductility. In addition, the oxide layer on the rod itself is eliminated. This oxide is another source of weld contamination.

The absence of a dropping and undercutting of the weld nugget, as is common when welding stainless steel without the addition of filler rod, is prevented by the back-up argon gas pressure. In the original tests, this pressure was somewhat high, resulting in a slight concavity on the underside of the weld. The excellent fluidity of the molten titanium also aids the formation of a smooth, flush weld nugget.

Effect of Welding Variables

It was found in subsequent tests that considerable improvement in the joint properties could be made by modifying the welding variables. During this investigation, considerable information was derived on the effects of welding conditions on the joint characteristics. MST Gr. III commercially pure titanium in the annealed and pickled condition was used for all tests. The joint design was a tight square butt type.

Effect of Backing Bar Materials and Configuration

Original tests used a copper back-up bar with a $^1/_4$ x $^1/_8$ in. "U" shaped groove. Tests were performed to evaluate the back-up bar material and the shape of the groove.

It was determined that the titanium deposited a slight smut on the copper back-up bar that built up and eventually was picked back up in subsequent welds, contaminating the titanium weld metal. Comparison between a copper back-up bar and a mild steel back-up bar of the exact same configuration indicated that the high conductivity copper sapped enough heat out of the weld during the welding operation to require an increased current setting. Increasing the current re-

sulted in added weld contamination. The use of a low thermal conductivity mild steel back-up bar retarded the chilling effect of the back-up bar on the weld area sufficiently to enable the operator to reduce the current setting or heat input on the welding machine. The lower heat level reduced the air contamination of the weld metal.

The effect of the backing bar material on controlling the heat distribution in the weld area prompted an investigation of the shape of the groove in the backing bar. Varying the size and shape of this groove changed the heat transfer characteristics to a marked degree. The dimensions of the groove were found to vary with the thickness of the metal to be welded. It was determined that a rectangular groove 3T wide by 3T deep, where T is the thickness of the metal to be welded, gave the optimum conditions of partial preheating the weld and cooling the fused joint to result in maximum ductility. The low thermal conductivity of the backing bar had to be balanced against a fairly rapid quenching type of backing groove to give an optimum thermal history to the weld. While no weld area temperature curves were made, the material itself was sensitive enough to the variations in temperature to indicate optimum conditions by a single bend test parallel to the weld. The thickness of the back-up bar was 0.5 in. Variation of the thickness of the back-up bar had no effect on the resultant weld.

Effect of Hold-Down or Chill Bars

The hold-down or chill bars used for the original testing were made of mild steel $^1/_2$ in. thick by $2^1/_2$ in. wide, chamfered on the weld side at 45° angle to $^1/_8$ in. thick. It was found that the only change in configuration required to improve the weld was a chamfering to $^1/_{16}$ in. thick on the weld side instead of $^1/_8$ in. thick. This was necessary to enable the hold-down bars to be placed nearer the actual weld joint. It was found that the closer these bars were placed to the joint the less heat oxidized zone appeared on each side of the weld. It was possible to practically eliminate the typical blue oxide color that occurs in the base metal alongside the weld by optimum spacing of the hold-down bars. Figure 2 is a typical picture of the surface of the weld and weld area immediately after welding. It can be seen that the surface of the weld metal is bright and that there is, at most, only a trace of a heat oxidized zone on each side of the joint. The chill bars had to be tightly clamped to the work to have the required effect on the heat pattern in the joint during and after welding.

Cleaning Methods

The original tests were conducted on as-received material, solvent cleaned to remove handling dirt only. A hydrofluoric-nitric acid pickle and wire brushing were investigated to determine what effect the light oxide scale that is on as-received material had on weld ductility. A 4% hydrofluoric acid, 40% nitric acid bath was used to pickle the titanium sheet metal prior to welding. The metal was dipped for the time to visually remove the scale, withdrawn, and rinsed in running

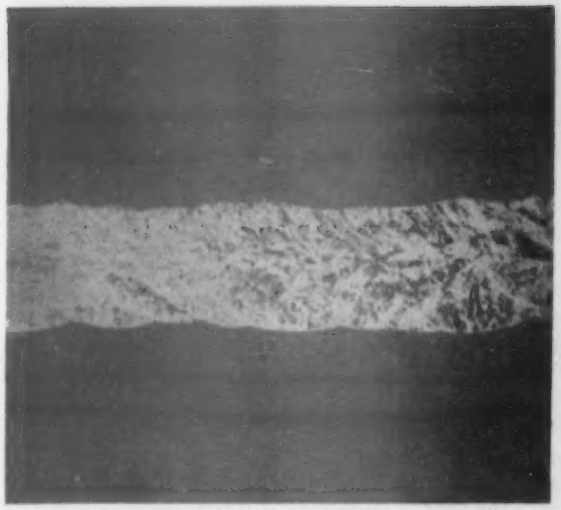


Fig. 2 Appearance of joint in welded sheet front

cold water, followed by hot water to facilitate drying. The time in the acid bath varies from one minute to as much as 15 minutes depending on the activity of the bath. It was found that this treatment removed the visible surface oxide and resulted in less weld contamination. Wire brushing was also tried using a stainless steel brush. The surface oxide in the area of the joint was more effectively removed by wire brushing than by the acid pickle. Oxygen and nitrogen contamination were practically eliminated on wire brushed joints. The degree of contamination was qualitatively measured by bend tests across and along the weld and by the surface color of the weld metal and adjacent base metal. It is felt that either of the two specific cleaning methods discussed should be required when welding titanium. The welding of as-received material is not satisfactory when compared to the improvement gained by acid or wire brush cleaning.

Effect of Welding Machine Settings

All tests were conducted using a 200 amp d c machine with a commercially available inert arc-welding torches, a ceramic cup and a $^1/_{16}$ in.-2% thoriated tungsten electrode. It was determined that the higher the machine settings were, the greater was the gas absorption into the weld metal. To keep embrittling gases entering the weld to a minimum, the lowest possible current setting or heat input was used. The mild steel back-up bar did much to lower the current necessary to complete a sound joint. The original setting of 70 amps was reduced to 25 amps for the same material thickness, 0.040 in., by the improvements in welding conditions made during the course of the investigation. This low current input considerably reduced the total amount of heat at the weld and increased the ductility of the resulting joint. A setting of straight polarity was used throughout.

Effects of Argon Flow on Top or Face of Weld

To determine the effects of argon gas pressure on the weld face, tests were performed at several different

pressures. The distribution of the gas around the weld puddle was improved considerably by the absence of a filler rod penetrating the argon blanket. A more protective, unimpaired blanket was created that flowed around the actual molten zone in a more symmetrical manner. It was found that the gas pressure setting is fairly critical and that it varies with the metal thickness and machine setting. The higher the current and the greater the thickness, the higher the gas flow. If too high a pressure is used, two undesirable conditions occur. The fused joint has concave areas along its face due to an actual depression of the weld by the argon pressure. This is not an arc blow phenomenon but is, rather, a simple pressure depression area in the weld. In addition, the close proximity and configuration of the chill bars produces a valley in the joint region. The high argon pressure in the area creates a gas flow pattern that tends to roll contaminating air into the joint. Reduction of this pressure to a critical value results in an optimum protection of the joint. The effect of argon pressure out of the ceramic cup is particularly important in material 0.050 in. thick and thicker. On 0.040-in. material, the argon flow rate out of the cup was reduced from 20 cfh in the original tests to 12 cfh in the final tests.

Effects of Argon Flow Rate on the Bottom of the Weld

Gas pressure on the root side of the weld is the key to welds of the fused, no filler metal added type. It is the dual function of the back-up gas to protect the weld from air contamination and to create a pressure that will prevent the fused weld metal from dropping through forming a convex protrusion on the underside of the weld and a concave depression along the top surface. The flush weld, top and bottom, that results from the fusing of the base metal, is a mark of the flowability of the molten metal and the presence of a critical argon pressure in the back-up groove.

The back-up pressure must be closely controlled. If too great a pressure is used, the weld root will be concave in shape and will contain pits at the gas port positions. In some instances, the pressure has been great enough to blow out through the weld face. The pressure has to be regulated to the thickness of the metal.

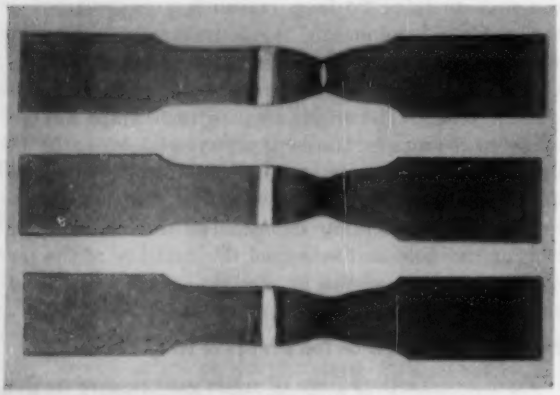


Fig. 3 Tension specimens after failure

The absolute value of the flow rate is low and the variation throughout the range of metal thicknesses tested is limited. The optimum flow rates were determined to vary from 1 cfh to 5 cfh for each 6 in. of joint length. For the 0.040-in. material the flow rate was reduced from 10 cfh in the original tests to 1-2 cfh in the final tests.

Using low pressures made the manner of distributing the argon along the back-up groove very important. The spacing of gas ports along the back-up groove was 6 in. apart. The first port was located about 2 in. in from the edge of the sheet. The length of the individual argon tube to each port became critical. To equalize the pressure over the entire weld, all the tubes leading to the gas ports had to be the same length and distance from the gas manifold.

Final Welding Conditions

Summarizing the results of investigating the effects of welding conditions on the strength and ductility of fused welds in commercially pure titanium, the following welding conditions were decided upon for experimental production joints:

1. Welding machine—200 amp machine, inert-arc welding torch, ceramic cup, and $^1/_{16}$ in.-2% thoriated tungsten electrode.

2. Back-up bar—0.5 in. thick mild steel bar with rectangular groove 3T deep by 3T wide where T is the thickness of the metal to be welded. One-eighth in. holes for argon back-up gas to be placed approximately 6 in. apart along the base of the groove starting 2 in. from the edge of the joint.

3. Hold-down bars—Mild steel bars $^1/_2$ in. thick by $2^1/_2$ in. wide chamfered on the weld side at 45° angle to $^1/_{16}$ in. thick. Bars to be placed as close to the weld as possible and tightly clamped.

4. All metal to be welded should be either pickled in a 4% hydrofluoric acid, 40% nitric acid bath for 1–15 min. until scale is visually removed or wire brushed with a stainless steel brush prior to welding.

5. Machine settings shall be as low as is possible to produce a 100% penetration weld. For 0.040-in. titanium, settings shall be current: 25 amp; voltage: 25 amp. The welding is done on d c, straight polarity.

6. Argon flow through welding torch shall be 12 cfh for 0.040-in. titanium and shall vary with metal thickness.

7. Argon flow for back-up groove shall be 1–2 cfh for each 6 in. of joint length for 0.040-in. titanium and shall vary with metal thickness.

8. Manual welding speed should be approximately 3 ipm for 0.040-in. titanium. Figure 1 is a general view of the test setup used in this investigation.

Strength and Ductility of Welds

The principal shortcoming of fusion welds in commercially pure titanium to date has been the low ductility of the resulting joint. The tensile strength of titanium fusion welds is that of the base metal or a little higher. A joint efficiency of 100–110% is assured in a sound weld. However, the ductility of the joint

made with the addition of filler rod, can range from 0% elongation in 2 in. in a totally embrittled weld to 15–18% elongation in an exceptionally ductile weld. Bend ductility is also affected. In general, it can be stated that the bend ductility of the weld has always been somewhat less than that of the base metal the weld is made in. Fusion welding without rod has changed this picture markedly.

1. Tensile Strength

Since the weld metal is stronger than the base metal, a standard sheet metal weld test is not indicative of the actual strength of the weld. As can be seen in Fig. 3, the base metal necks and fractures before the weld metal or weld zone. The fracture strength is that of the base metal, in this case averaging out to a yield strength of 84,500 psi, an ultimate tensile strength of 102,500 psi and an elongation in 2 in. of 18.5%. Some tests made on fusion welds with weld metal added, cast some light on the performance of the weld zone itself. The specimens were pre-necked at the weld zone and then tested to fracture. It was found that these specimens exhibited a weld zone tensile strength of 130,000 psi and a local elongation at the weld of about 8–10%. It is felt that the properties of a fusion weld made without filler rod will lie someplace between the two sets of values presented above, probably very near the properties of the base metal.

2. Hardness Survey

A hardness traverse of the base metal, heat-effected zone, and weld metal, indicated that the heat-effected zone and weld metal were slightly softer than the base metal. The base metal average hardness was R_c 21.5. The heat-effected zone was R_c17 and the fused zone was R_c19.

3. Bend Tests

The bend test of a sheet metal fusion weld is an excellent indication of its ductility. For the purposes of this investigation, the welded samples were bent over a 2T radius (T = metal thickness). Table 1 is a summary of the bend test results.

It can be seen that there is a significant improvement in the ductility of a weld made with no filler rod added over that made with filler rod added. There is an added improvement in ductility when the welding conditions under which the fused welds are made is improved. Figure 4 shows the bend samples parallel to the weld after bending. The specimens at the top contained filler rod. The samples at the bottom left were welded without filler rod and bent along the weld. The sample at the right was bent along the heat-effected zone. This sample had not failed at 190° bent over a 2T radius mandrel and was further flattened in a vice. A base metal sample fractured under these conditions. The fused or no rod added weld sample had still not fractured. Figure 5 shows, on the left, a bend sample across the weld where filler metal had been added. On the right is a fused weld made without rod. Figure 6 shows samples bent diagonally 45° across the weld. The sample in the upper left was made with filler rod. The sample on the right was made without filler rod. These pictures show graphically the improvement in weld joint ductility made by welding without the addition of filler rod.

Table 1—Bend Angle to Failure

Sample History	*Bend parallel to weld (2T radius)*	*Bend across weld (2T radius)*	*Bend at 45° to weld (2T radius)*
Welded with rod	115°	115°	65°
Original test without rod	160°	145°	120°
Final test without rod	190°	190°	190°
Base metal	180°	..	..

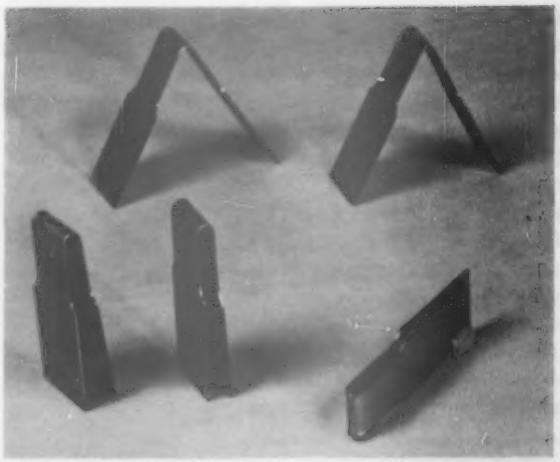


Fig. 4 Longitudinal bend tests

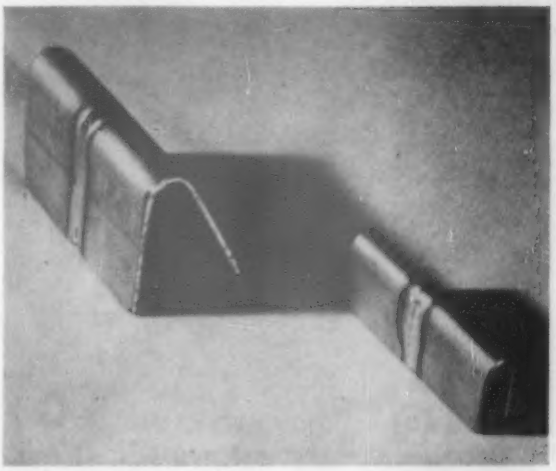


Fig. 5 Transverse bend tests

The ductility of a titanium fusion welded joint can be roughly determined by the surface color of the weld. This statement applies to original welds only, not to rewelds. The amount of gas contamination and resultant embrittlement in the weld is indicated by the thickness of the oxide layer that appears on the sur-

face of the weld metal. As this oxide layer grows in thickness, it goes through a scale color phenomenon similar to that of steel. Table 2 lists these colors and the resultant bend angle to failure. The fusion welding specification for titanium at Marquardt is written to limit acceptable fusion welds to those with a light straw color or bright silvery appearance on the weld metal surface only. A dark straw, blue or gray color or free scale on the surface is cause for rejection of the weld and the part. It has been found that the bright silvery appearance is much easier to obtain when no weld rod is added than when weld rod is added. All the bend test comparisons made in this paper, whether with rod or without, are made with welds that had a bright silvery appearance.

Table 2—Color Indications of Weld Ductility

Weld metal surface color	*Bend < to failure over 2T radius*
Silver	180+ (no rod added)
Silver	115° (rod added)
Light straw	88°
Dark straw	71°
Light blue	66°
Dark blue	21°
Gray blue to free scale	0°

4. Metallographic Examination

A metallographic study of joints made with and without filler metal disclosed some marked differences in the microstructure of the two welds. The microstructure of the weld made with filler rod consisted of a typical coarse grained basketweave alpha structure in the weld, an area in the heat-affected zone of coarsened grains of acicular alpha and a base metal structure of fine grain equiaxed alpha with some acicular alpha. These structures are typical of the structure to be found in a titanium sheet metal fusion weld.

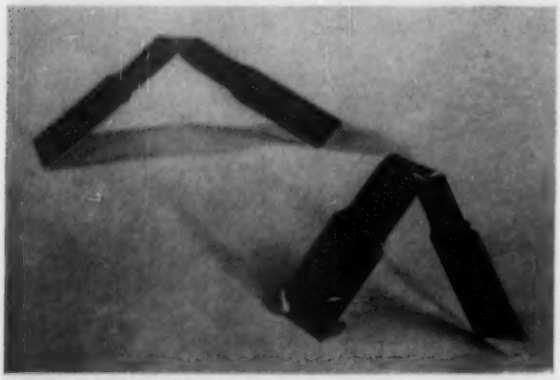


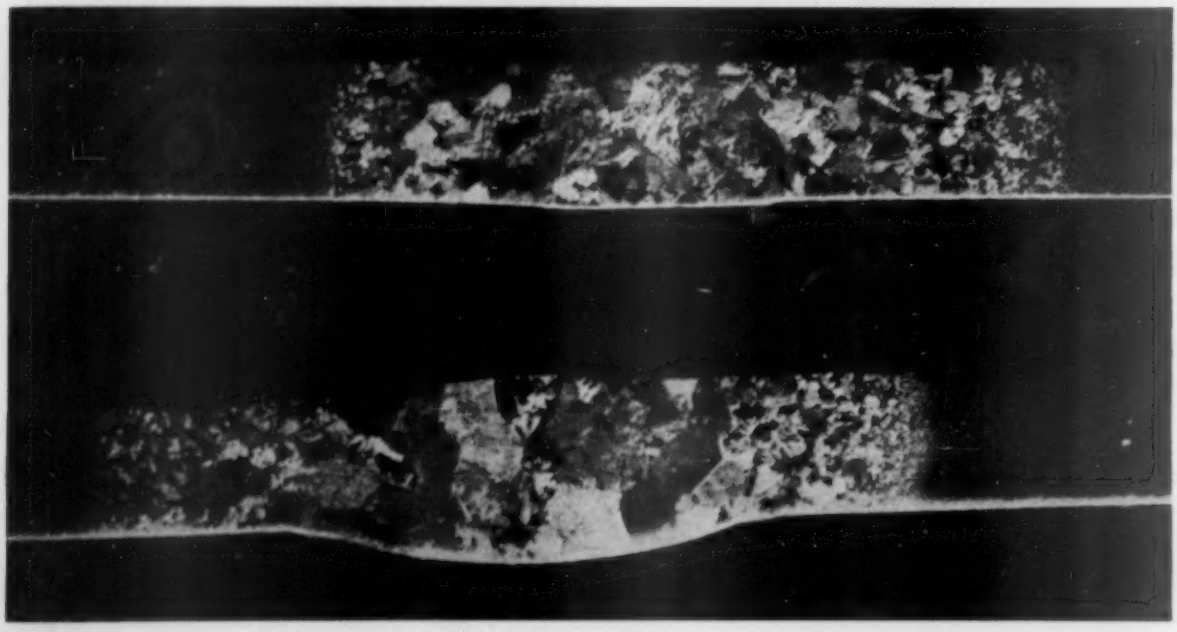
Fig. 6 Bend test 45 deg across the weld

The microstructure of the weld made without adding rod differed from the rod added weld primarily in two respects. The area of the coarsened acicular alpha structure in the heat-affected zone was smaller and more sharply defined and there appeared to be some needles of retained beta in the fused zone basketweave alpha. Both of these occurrences are evidence of the lower heat input of the welds made without rod and the resultant faster cooling. Figure 7 shows cross sections of welds made with and without added filler metal.

5. Production Parts

The no rod added fusion welded joint has been successfully tried in limited production and is now successfully performing in service applications. Figure 8 is a titanium assembly of some complexity that contains fusion welded joints of considerable length that were made without adding any filler rod. In addition, this assembly contains considerable resistance welding, a

Fig. 7 Cross section of welds made with and without filler metal



hot spun "Z" ring, several hot formed bathtub type parts some of which have been contour fusion welded without rod added, riveted fasteners and several other sheet metal fabrication techniques. The part is used on a turbojet engine and saves considerable weight over the use of steel for the application.

To date, the no rod added welds have been principally used on longitudinal tight butt joints made manually in commercially pure titanium 0.062 in. thick or thinner. However, with further work and the aid of new automatic welding devices such as illustrated in Fig. 9, it is felt that these limits will be erased. The use of the universal type inert-arc welding machine shown, that can weld longitudinally, circumferentially or over a contour with equal ease, will permit the welding of titanium in any shape and over a wide range of thicknesses without adding filler rod. It is also felt that the technique of welding without rod, either manually or automatically, will be suited to the welding of weldable titanium alloys as well as commercially pure titanium.

Conclusion

Welding titanium sheet metal is no longer the problem it started out to be. Using the latest techniques, with the addition of filler rod and especially without filler rod, entirely acceptable welds can be produced for the most severe service. For maximum ductility, equaling or surpassing that of the base metal itself, fusion welds made without filler rod should be used wherever possible.

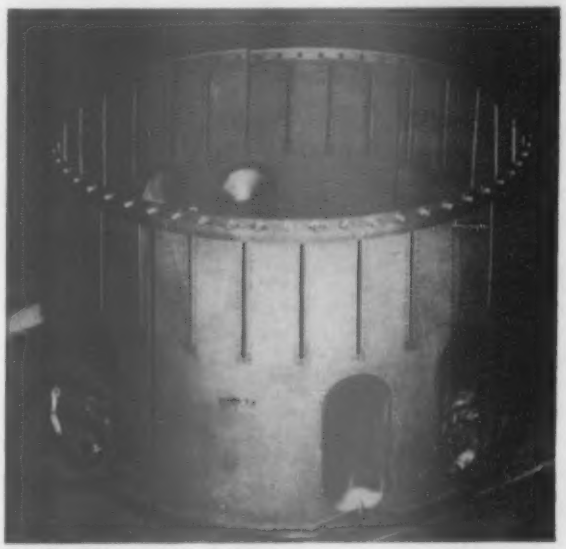


Fig. 8 Titanium turbojet engine parts

Fig. 9 Machine for automatic nonconsumable-electrode inert-gas welding

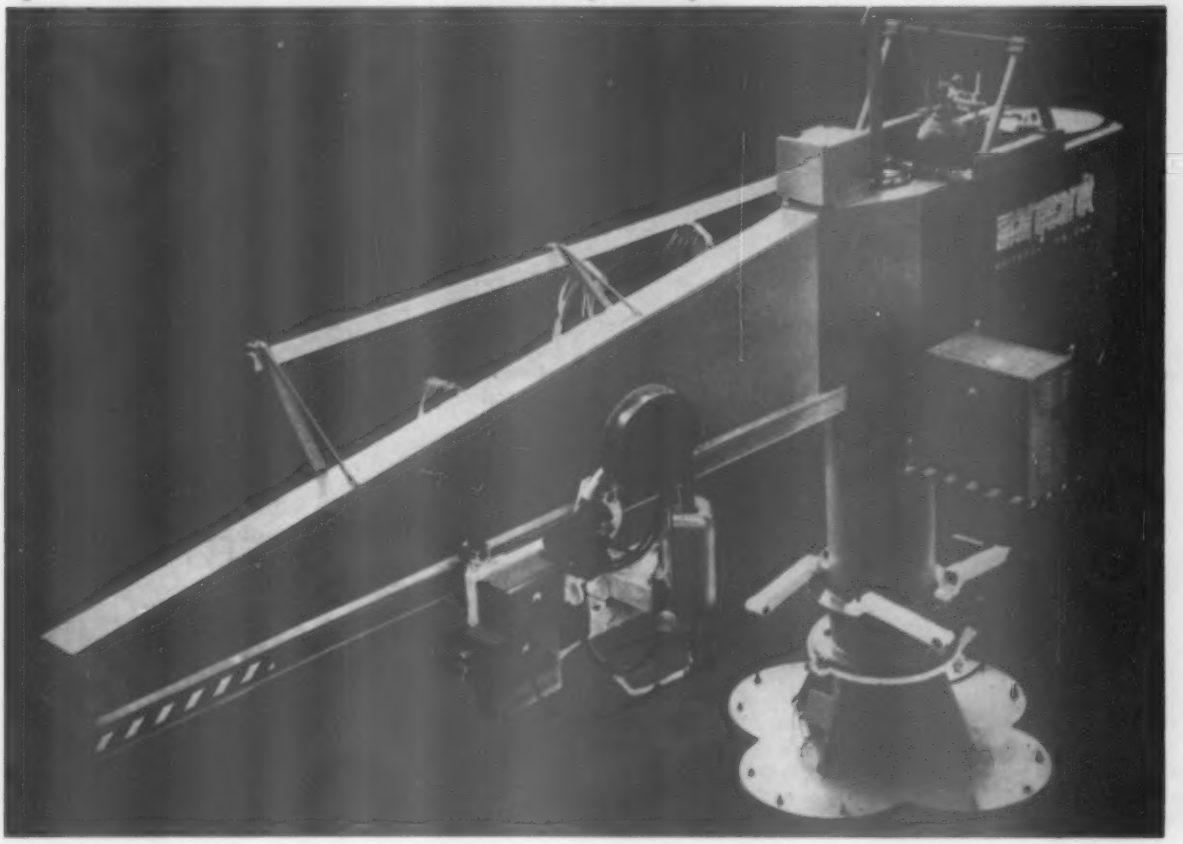


Fig. 1 Nothing can replace the actual testing of the brazing application

METALLURGICAL PROPERTIES OF SILVER-CADMIUM-COPPER-ZINC BRAZING ALLOYS

Formation and physical properties of metallurgical phases of the Ag-Cd-Cu-Zn quaternary alloys investigated and discussed by author

BY KARL M. WEIGERT

SYNOPSIS. The formation and physical properties of metallurgical phases are described in this paper by establishing sections through the silver-cadmium-copper-zinc quaternary system.

From the interpretation of thermal analysis data and the correlation of microscopical observations, recommendations could be made for the practical applications of popular brazing alloys. The alpha and beta phases of the cadmium and zinc rich silver-copper alloys were identified and the mechanism of peritectic reactions taking place during the solidification process was described.

Colored photomicrographs played an important part in the analysis of phases and details of solid solubility.

Previous Investigations

The older silver-copper-zinc alloys of inherent high brazing strength have been described previously.[4] It is commonly known that by introducing cadmium bearing phases the melting and brazing ranges were lowered considerably.

It was undertaken in this paper to describe the technically used alloys of the quaternary system from the metallurgical point of view. Only alpha and beta phases were considered to fall into the scope of the investigation, since they are workable and produce strong joints. From the phase diagrams predictions about limitations and shortcomings of brittle phase could be made.

Experimental Methods and Procedures of Determining the Physical Properties of the Quaternary Alloys

Determination of Liquid-Solid Transformations

The liquidus temperatures were determined from cooling curves taken in the conventional manner with a chromel-alumel thermocouple and registered by a Leeds and Northrup recorder. Open thermocouples were attacked and dissolved by the corrosive silver alloys. Porcelain tubes offered some protection, but introduced a lag in the heat transfer. The best results were obtained with the so-called "Marshal Tip" thermocouples. In this construction, the thermocouple wires are swedged into a thin tip of highly corrosion-resistant steel. The accuracy and reproducibility of the thermal effects were 5 to 10° F.

Preparation of Samples

For the investigation of each diagram section, 20 to 30 ounces of an alloy containing only silver-copper-zinc and silver-copper-cadmium were compounded and analyzed to conform with the nominal compositions to about 0.25%. From the melting losses in zinc and cadmium, such deviations could be predicted and anticipated by the necessary additions in remelting. The intermediate compositions were obtained by blending the various zinc and cadmium master alloy composi-

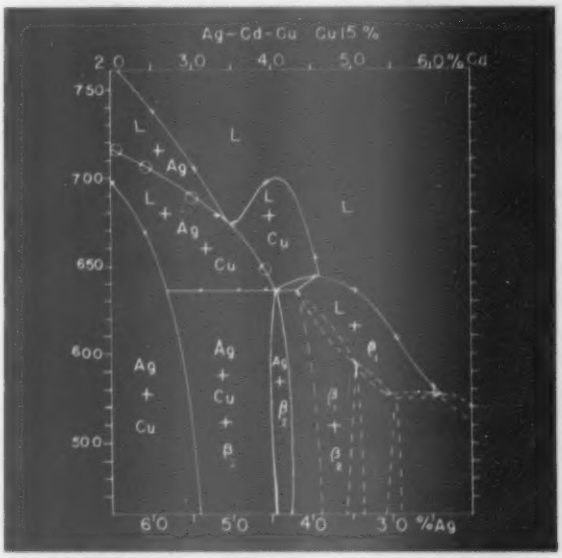


Fig. 2 Vertical section through the Ag-Cd-Cu diagram at 15% Cu is of special interest since the low flowing solders contain about this amount. Note the fluctuations of the liquidus temperatures which recurs in the quaternary alloys

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Paper to be presented at the AWS National Spring Meeting to be held June 7-10, 1955, Kansas City, Mo.

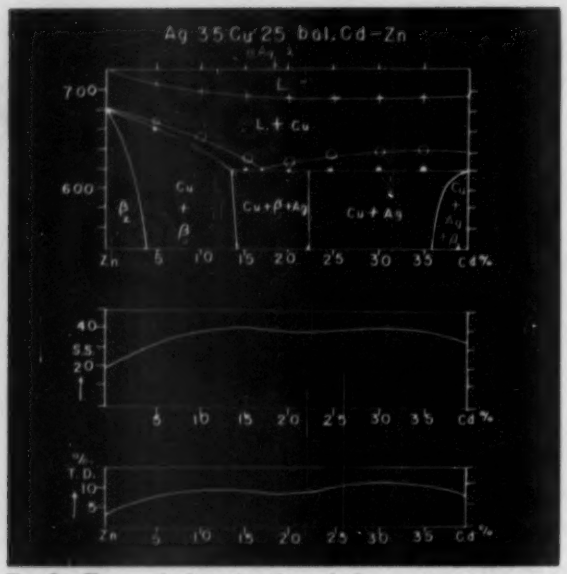

Fig. 3 The vertical section through the quaternary system Ag-Cd-Cu-Zn at 35% silver and 25% copper shows that the alloy BAg-2[5] is chosen for low melting temperature and high strength

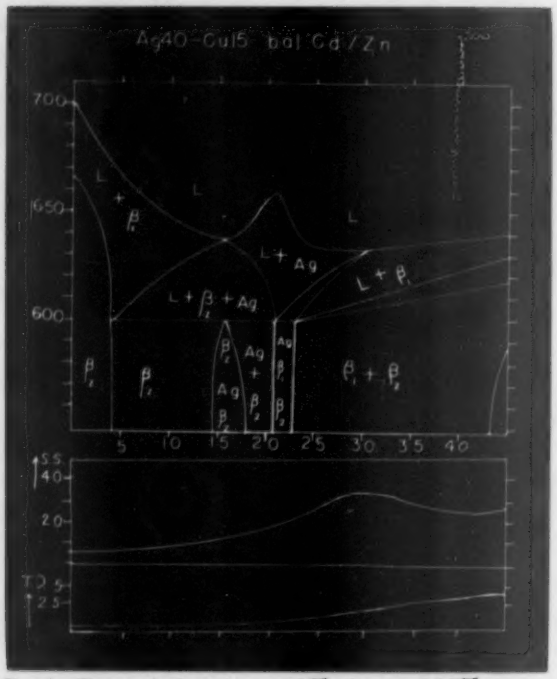

Fig. 4 The vertical section at 40% silver and 15% copper shows that considerable amounts of cadmium are necessary to give low melting temperature and high strength at the same time

tions. Since this takes place at relatively low temperatures, mostly below 1500° F, deviations from the nominal compositions could be kept below 0.1%.

Three to five ounces of each composition were set aside for thermal testing, casting of 1/4 in. rods for testing of strength and microscopical observations.

Testing of Strength and Ductility of Alloys

Testing for tensile strength and elongation on cast samples requires a great number of specimens and lacks in accuracy, due to the imperfections along the test pieces. It was found to be much easier and more accurate to determine the shear strength and traverse ductility. Only three tests on each composition were sufficient to reproduce the same values with from 2 to 5% of accuracy. The simple apparatus consisted of three plates clamped together, so that the middle plate moved against the outside plate in the opposite direction. The 1/4-in. sample was inserted through a slightly larger hole in the three plates and then sheared apart in a tensile testing machine. Just before breaking, the sample was deformed into a crankshaft-like shape, and in most cases only one side broke off entirely. The linear displacement of the middle stump gave a measurement of the traverse ductility (T.D.) in percent and was plotted in percent against the shear strength (S.S.) in psi × 1000 (Figs. 3 to 6).

Microscopical Specimen

The method of preparing the specimen for microscopical studies has been described previously.[4] In a cylindrical brass piece of 1 in. diameter and about 1 1/2 in. high, holes were drilled lengthwise down to within 1/2 in. of the bottom. Leftover of pieces from the shear test were inserted into the holes, reaching almost to the top. Flux was applied to each hole, and the block heated until each alloy melted separately. It was checked repeatedly, that no appreciable diffusion took place between the brass and the alloys during the short time of heating and keeping the temperature below 1500° F. By slow cooling of the specimen, large crystals were produced during the solidification, which helped considerably in the identification work.

The specimens were ground, polished and etched for microscopical observations. A small slice of the block could be retained as a record of the as-cast condition. In order to establish phase equilibrium below the solidus temperature, all specimens were first subjected to a heat-treatment of 500° C. In 5 to 10 hr, this process was mostly completed, and no changes observed afterward. An investigation of phase changes toward lower temperatures was not within the scope of this investigation.

Phase Diagram Sections

Nomenclature of Phases

Phases derived from the Ag-Cd diagram are indexed Ag and beta$_1$. Phases derived from the Cu-Cd system are indexed: Cu and beta$_3$. The silver-zinc alloys are indexed Ag and beta$_2$. Since the Ag-Cd and Ag-Zn beta phases form continuous series of solid solutions (1) beta$_1$ and beta$_2$ are identical phases. Differences,

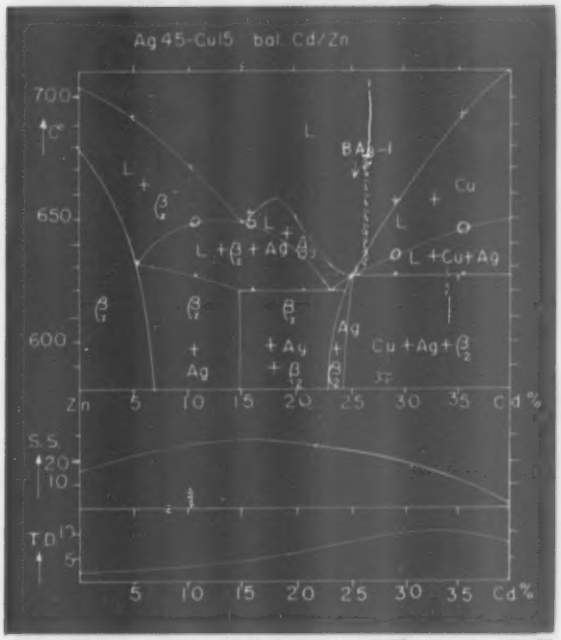

Fig. 5 The vertical section through the 45% silver and 15% copper diagram shows the reason for the popularity of BAg-1.[5] It combines a low liquidus and a narrow melting range with considerable strength

however, can be seen in the color tints of the photomicrographs.

Physical Properties of Phases

The physical properties of the silver copper and copper-zinc alloys are sufficiently known. The silver-cadmium beta$_1$ phase (Ag-Cd) has quite suitable properties for brazing alloys, e.g., relatively low melting and flow points and remarkable ductility and strength compared to the Ag-Zn beta$_2$ phase. The copper-cadmium beta$_2$ phase (Cu_2Cd) or 3:1 atomic percent has a low melting point which recurs in the features of the quaternary alloys. Otherwise this compound is extremely brittle and can only be utilized in connection with other phases. The complications of the Ag-Cd-Cu diagram (Fig. 2) are caused by the immiscibility of the beta$_1$ and beta$_2$ phases.[1] This results in a number of two and three phase fields in the solid state.

The pink color of the Ag-Cd beta$_1$ phase remains within the additions of copper. The color of the copper-cadmium beta$_2$ phase changes from blue to brown when etched with ferric chloride.

The Vertical Section Through the Ag-Cd-Cu Diagram at 15% Cu

Since the very low melting and flowing quaternary silver solders have an approximate copper content of 15%, it seemed to be of interest to investigate the section through the ternary Ag-Cd-Cu diagram at 15% copper. The results are shown in Fig. 2. The occurrence of strange maxima in the liquidus curve previously described[6, 7] can be explained by transitions of primary copper to silver-rich alpha and silver-rich beta phases. The reaction mechanism is of the peritectic type where the liquid reacts with the primary copper or silver crystals and forms the beta$_2$ phase of the copper-cadmium system (Cu_2-Cd) at a relatively low solidus temperature of 635° C. With a cadmium content higher than 40%, a lower melting temperature results in the formation of the phases beta$_1$ and beta$_2$. Increasing brittleness makes these alloys of doubtful practical value.

After a critical study of alloys in the Ag-Cd-Cu and Ag-Cu-Zn system the beneficial effects of the two systems could be seen in the formation of lower melting and flowing alloys and an increase in brazing strength over the zinc free alloys.

Sections Through the Quaternary System

1. Ag 35, Cu 25, balance Cd-Zn 40%,[8, 9] Figs. 3,7 (Example BAg-2). Solders with about 20–35% silver are used for relatively high temperature applications of lower cost solders. In the primary crystallization at about 700° C copper dendrides appear. Later at 630° C at the solidus temperature the silver and the silver-zinc beta$_2$ phase solidify. Strength and ductility change little with concentration. The high strength copper- in the silver-beta$_2$ field corresponds to the findings in the Ag-Cu-Zn system.[4] The cadmium is dissolved by the silver rich phases Ag and beta$_2$.

2. Ag 40, Cu 15, balance Cd-Zn 45%, Figs. 4,8. The relatively low liquidus temperatures and the low silver content have made this series of alloys attractive.[7] It can be seen that for highest strength and ductility a considerable amount of cadmium is essential. Some of the minima in the liquidus temperatures can be explained by the transition of two different primary crystallizations: beta$_2$ to Ag and Ag to beta$_1$.

3. Ag 45, Cu 15, balance Cd-Zn 40%, Figs. 5,9 (Example BAg-1). The popular 45% silver alloy with 25% Cd precipitates primary silver and copper crystals simultaneously at a temperature minimum. The strength is higher at lower Cd values but the ductility is rather poor. An indication for the two strange minima in the liquidus curve is again the transition of the beta$_2$ phase into the silver phase and the transition of the silver to the copper phase.

4. Ag 50, Cu 15 balance Cd-Zn 35%, Figs. 6–10 (Example BAg-1a). Small changes in the copper and cadmium content are very critical in regard to the liquidus temperatures. The alloys are higher flowing than the 45% silver compositions but the ductility is somewhat better.

Other sections have been worked out for compositions that might have future technical applications. These few examples should demonstrate the basic mechanism of solidification.

General Conclusions

During the course of the investigation certain views could be confirmed:

1. A combination of the Ag-Cu-Zn and Ag-Cd-Cu

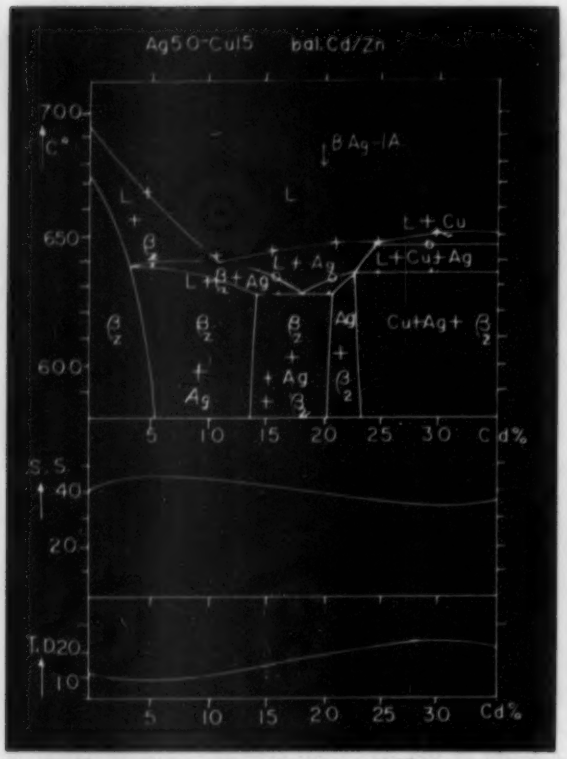

Fig. 6 The vertical section through the 50% silver diagram with 15% Cu shows the advantages of the old standby BAg-1a[5] in ductility and strength

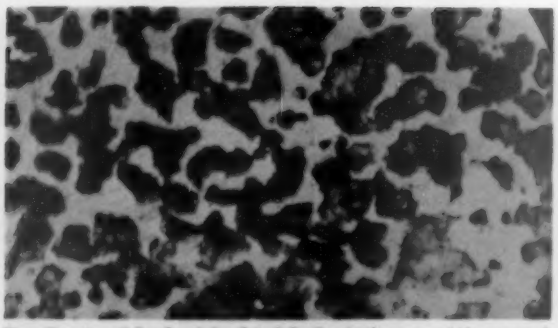

Fig. 7 Ag 35, Cu 25, Cd 25, Zn balance. Micrograph ×300 taken from Fig. 2. The brown copper and light silver phases form a strong but higher melting alloy

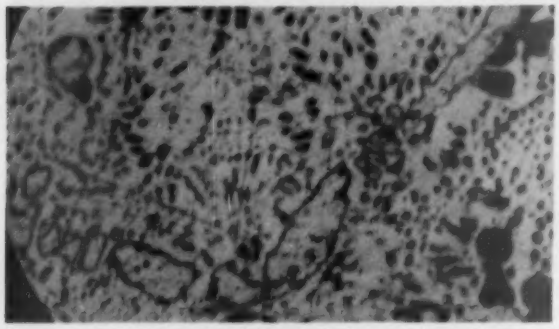

Fig. 8 Ag 40, Cu 15, Cd 27, Zn balance. The alloy contains the silver and copper beta phases and combines fair strength with relatively low flowing temperatures

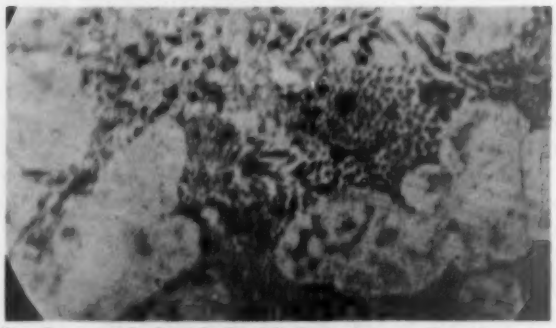

Fig. 9 Ag 45, Cu 15, Cd 25, Zn balance. This alloy derives its properties from the soft silver and the low melting cadmium phases

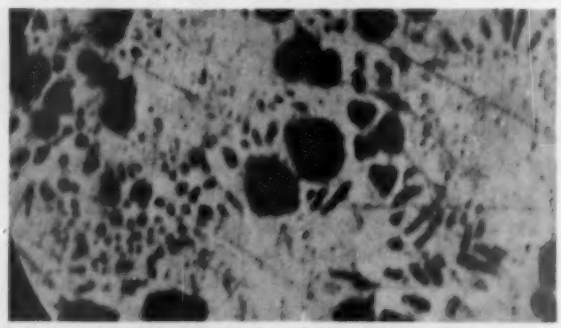

Fig. 10 Ag 50, Cu 15, Cd 18, Zn balance. This solder shows high strength with good ductility

systems sufficiently describes the quaternary system in the commercially used alloys.

2. Commercial Ag-Cd-Cu-Zn solders are based on the Beta phases of the Ag-Cd, Ag-Zn and Cu-Cd, Cu-Zn systems respectively. The alpha phases are high flowing and the gamma phases brittle. The Ag-Cd beta$_1$ phase is quite ductile and a basic constituent of commercial alloys together with the low melting Cu$_2$-Cd beta$_2$ phase.

3. The quaternary alloys have gained their popularity mainly by the lower brazing temperatures. Tensile strength values were found up to 60,000 psi.

Acknowledgment

Thanks are due to Andrew R. Devereux, head of the Research Department of Goldsmith Bros. Smelting & Refining Co., for his permission to publish the experimental results.

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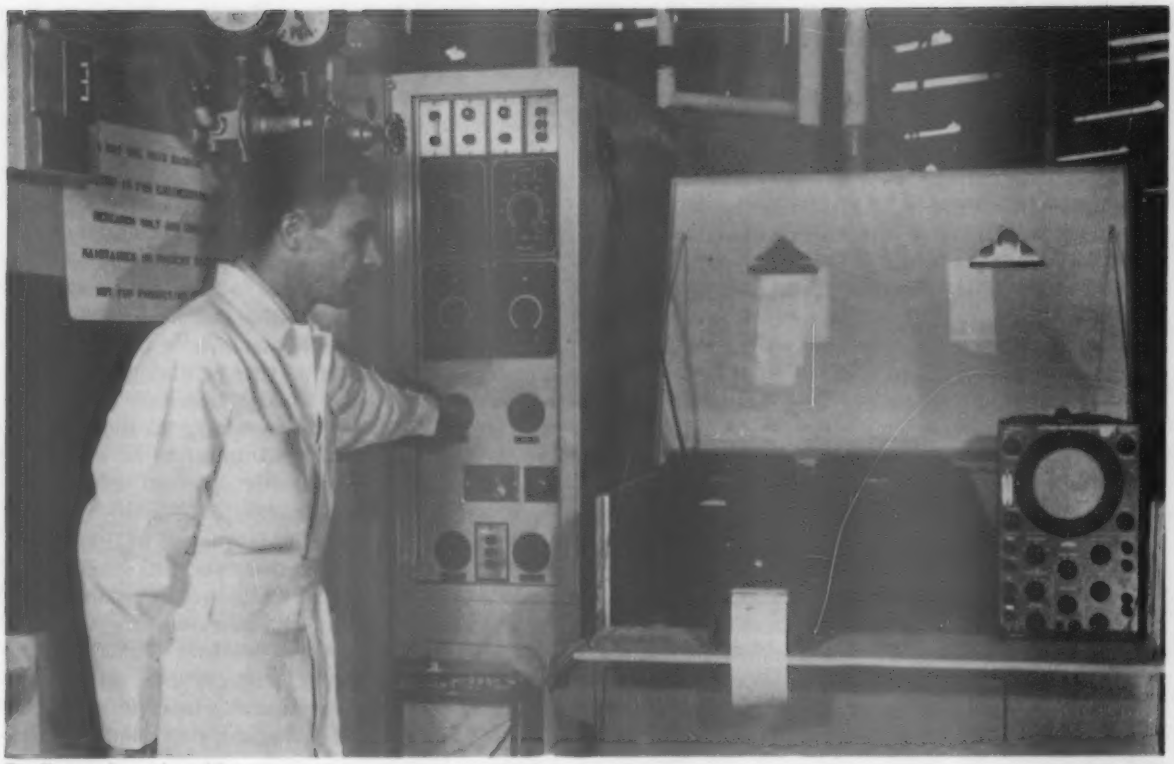

Oscillographs with welders

OSCILLOGRAPHIC INSTRUMENTS IN SPOT WELDING QUALITY CONTROL AND MAINTENANCE

Cathode-ray oscilloscope and direct writing magnetic oscillograph are described as being useful and necessary tools for welder maintenance under a high requirement quality control program

BY GLENN WOODMANCY

ABSTRACT. Quality control systems for resistance welding have one common factor and that is proper means for assuring dependable welding machine performance. Experience has shown that service of 3-phase spot-welding machines cannot be effectively performed without either the cathode-ray oscilloscope or direct writing magnetic oscillograph. In most cases both are needed.

The goal of proper welder maintenance is to isolate the cause of malfunction and correct it rather than to juggle components for a temporary fix. This goal must be achieved for welding schedule reliability.

Three-phase frequency converter welders are particularly suited to the use of the oscilloscope because they can be operated so that various signals recur at a high enough frequency to be read on the oscilloscope. Once operating personnel become familiar with the correct signal patterns at various places in the welder, they can diagnose malfunctions.

This paper discusses timing calibration, timing synchronization, current control dial calibration, weld pressure calibration, pressure and current correlation, ignitron balancing and timing control check-out.

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Introduction

Quality control of resistance welding has received the attention of several writers during the past few years and many systems of quality control have been de-

scribed and their advantages extolled. Regardless of what system is being used, however, there is one common factor and that is properly operating welding machines. No quality control system can be economical or effective unless the machine doing the work is performing dependably and with consistent results. Matthews[1] has stated, "the best resistance welding equipment in the world is no better than the routine or preventative maintenance schedule that has been established for that equipment." This same author[1] has made reference to the subject of this article by pointing out that "at the time of initial certification, certain standards and calibrations are made for later reference during overhaul or in case of machine breakdown or replacement of major parts. The calibrations are accomplished by using oscilloscope or oscillographic equipment." The use of these instruments for these calibrations and other uses connected with 3-phase resistance welder maintenance will be discussed in this presentation.

Maintenance of 3-phase welders cannot be done effectively without either the cathode-ray oscilloscope or direct writing oscillograph. For efficient and fully effective work both are required. The least expensive is the cathode-ray oscilloscope and fortunately it is the most useful. This instrument, for many years of its existence, has been considered laboratory apparatus and not suitable for routine production shop maintenance work. This presentation hopes to show that this is not the true situation. Instead, it will show that the subject instruments are invaluable tools to a maintenance group charged with the responsibility for welder maintenance. These instruments make possible visual observation of the over-all performance of welders as well as performance of various control components. Without the visual presentation of the various actions, an accurate picture for performance analysis is impossible. Without accurate analysis, the real cause of machine malfunction is not isolated and corrected. This isolation of the real cause of machine difficulties is absolutely necessary to prevent juggling of control components in such a way that welding schedule reliability is affected. Without welding schedule reliability, no quality control system can remain effective for long.

Although all industries do not do their spot welding by certified welding schedules, all industries are concerned with a minimum of nonproduction time and a minimum of rejected parts. In any case, the machine maintenance should be such that a selection of machine settings once established for a given part of joint need not be re-established for lack of machine calibration or standard operating conditions. This calibration can be achieved by use of the subject instruments.

Three-phase frequency converter welders are particularly in need of adequate, effective and rapid maintenance. Fortunately, they are also the most adaptable type of modern electronically controlled welder to the use of the subject instruments. This is because the various signals can be made recurrent at a high enough frequency to be observed as a stationary image on the screen of a cathode-ray oscilloscope. Extremely low frequency or nonrecurrent signals require the use of the direct writing magnetic oscillograph. The operating characteristics of the frequency converter equipment are particularly convenient because for a considerable amount of routine maintenance or trouble shooting, complete weld sequencing is not necessary and the equivalent of hours of welding can be observed in a matter of minutes.

Some performance factors of spot welders are best observed with the aid of the cathode-ray oscilloscope and some with a direct writing magnetic oscillograph. The choice of which to use depends on the limitations of each. As mentioned previously, the signals need to be recurrent at a high enough frequency to be synchronized with the sweep generator of the cathode-ray oscilloscope for that instrument to be used. All other signals are conveniently observed only on the direct writing oscillograph.

This discussion of instrumentation of welders is confined to oscillographic instruments but it should be realized that these instruments are only part of the complement of instruments necessary for complete maintenance of resistance welders. Fullerton[2] has listed the following very complete list: tip pressure gage, oscilloscope, oscillograph, tube tester, millivoltmeter, strain gage equipment, stop pointer meters, clamp-on transformers, cycle counter, vacuum tube voltmeter and volt-ohm-milliampere meter.

The two instruments on this list that are the subject of this presentation have uses which can be classified under the following topics: timing calibration, timing control check-out, timing synchronization, pressure and weld current correlation, phase shift calibration, weld pressure calibration and ignitron balancing. The first two are most closely related and differ only as to source of the signal that is being considered.

Timing calibration is the checking of the welding current variables and adjusting the welder so that the output of the welder agrees with the timer control dials of the welder. Timing control check-out is the examination of various signals at several locations in the control circuitry so that first stages of control are correct before examination of the welder output. This is simply a case of first things first. The most important timers to check and calibrate on any welder are the current timers. These need careful consideration.

Another topic listed above is timing synchronization. This has to do with the time relationship between current control signal and ignitron plate voltage. Failure to consider this factor can cause discrepancies of timing calibration. It will be discussed in more detail later as it applies to frequency converter welders.

Pressure and weld current correlation has mostly to do with forge delay timer calibration, but it also concerns things such as determining sufficient squeeze or hold time.

Phase shift or heat control curves of welder output vs. dial setting can be made with the direct writing oscillo-

graph for the information they can reveal about welder operating characteristics. Items of information such as the lower and upper limit of the effective portion of the control are of value to maintenance people as well as those who have to develop welding schedules.

Weld pressure calibration can be carried out easily with the direct writing oscillograph so that information about the operating characteristics of the welder can be obtained for study. This is not so significant for constant pressure welders but it is important for machines with variable pressure. Timing features of the pressure oscillogram are of value to maintenance personnel and to personnel charged with responsibility for development of welding schedules.

With frequency converter welders, the problem of ignitron balance can easily be solved with the cathode-ray oscilloscope as shown by this same author[4] in a previous paper.

At the present time, leading welder manufacturers are placing in the hands of their customers service bulletins and blueprints, both wiring and schematic, of the machines purchased. All purchasers of welding equipment should require complete blueprints and service bulletins in their purchase specifications because no maintenance department can operate effectively without them.

Service bulletins having the most value to a customer are those which either have oscillograms or line drawings of oscilloscopic traces for the many test patterns that need examination in the control cabinet of a welder. The details of where the scope is connected and what the pattern is supposed to look like will, of course, vary from one manufacturer's equipment to another and should be obtained from the service bulletins. There should be a certain order of checking in these bulletins and this should be followed carefully not only when checking a machine after installation but at other times as required. It is not enough to examine welding current patterns to locate a malfunction or poor adjustment; one must examine other signals within the control circuitry for proper diagnosis of malfunction.

Equipment and Accessories

Various scopes can be used for the purposes discussed in this presentation. However, three prime requirements must be met. They are as follows: (1) a P2 or P7 cathode-ray tube screen; (2) a sweep frequency as low as 1 cps; (3) vertical amplifier with good low-frequency response suitable for a 1 cps square wave. The absence of standardized scope nomenclature makes it extremely difficult to discuss scopes in general for the particular application being discussed in this presentation; therefore, the author has elected to discuss the use of Dumont 304-H scope and will be using the nomenclature of this instrument. It is up to the reader to translate this for the particular instrument he may have. The reference by Rider and Uslan, chapters 10 and 22,[3] will be of assistance in this connection.

Direct writing magnetic oscillographs suitable for the purpose being discussed are limited. To the author's knowledge only one such instrument is available and that is Brush Electronic Co.'s BL-213. There are many magnetic oscillographs with film recording available but they are inconvenient for routine maintenance.

Accessories necessary for the instruments described above are documented by other writers. Matthews[1] mentions the solenoid or toroid pick-up coil and integrating circuit for detection and recording of welding current. For this purpose, the author used an electrovalve coil and an integrating circuit of 12 mfd and 500 K ohms. Richter has completely analyzed the problem of detecting large magnitude currents such as those that are produced in resistance welders. As described in his paper, the integrating circuit is necessary to make the output voltage of the detecting circuit directly proportional to the welding current *magnitude* rather than proportional to the time rate of change of the current.

Voltage patterns at various locations in the welder control can generally be applied to the scope or oscillograph by alligator clip leads and suitable jacks.

Welding pressure transducers take various forms. However, all that are conveniently used utilize strain gages mounted on electrode holders, support arms or an auxiliary brace. The author has used both the auxiliary brace and a cantilever arm attached to the welder lower support arm. The latter is pictured in Fig. 1. Magnetic shielding is not required if the strain gage installation is noninductive. The arm itself is machined from 6061S-T4 aluminum and has a reduced cross section where the strain gages are mounted, two in tension and two in compression. This pressure transducer gives pressure oscillograms as shown in the oscillograms later in this presentation. The advantage of this transducer is that it minimizes undesirable signals such as floor vibrations and as a result, gives

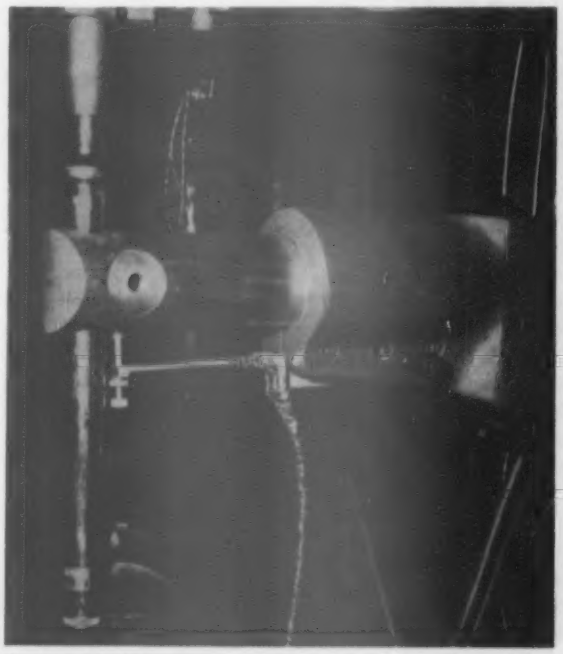

Fig. 1 Cantilever arm pressure transducer for welding pressure

Fig. 2 Phase rotation—control thyratron cathode to screen grid voltage

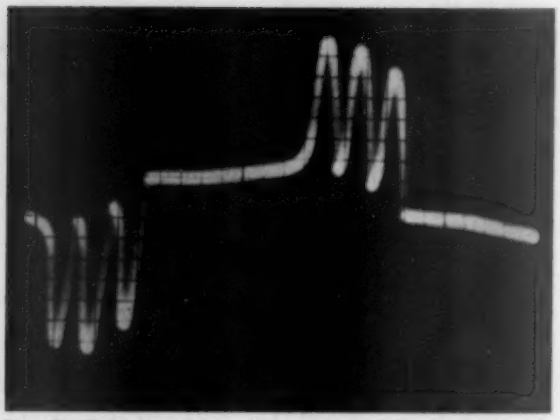

Fig. 3 Frequency converter current—full cycle with $^1/_{60}$ sec pulses

more accurate representation of the pressure acting on the weld.

Another piece of auxiliary equipment that is useful in some circumstances is an electronic switch. The situations that arise when two wave forms have to be observed simultaneously are the ones that require an electronic switch to be used with the Dumont 304 scope.

Use of Cathode-Ray Oscilloscope

Uses of the scope are control circuitry examination and welding current examination. As mentioned in the introduction, the details of control circuitry examination vary from one manufacturer's welder to another.

These details will have to be determined from the welder manufacturer's service bulletins. Lack of standardized controls or terminology prevents discussing any such details.

One check of control circuitry that is common for three-phase frequency converter welders is a check of phase rotation. At the time of welder installation, or anytime after this when the power lines to the welder may be changed, a check of phase rotation must be made before the welder is operated. This can be easily done with the scope in the following way: connect the hot side of the scope to control thyratron screen grid and ground side to the cathode of the same tube. If phase rotation is correct, i.e., if power lines are correctly connected to the welder, the pattern on the scope will move to the left as the heat control is advanced. The pattern that is obtained on each thyratron screen grid is that of Fig. 2. For this check the weld current does not need to be flowing. Proper precautions should be exercised by the personnel performing this test because of the high voltage.

A most important use of the oscilloscope for any welder is calibration of the welding current timers. This should generally be done first on the output of the control panels without having power tube plate voltage on until one has determined that the control will not be wild and allow damage to the welder. This can be done according to service bulletin instructions.

The final calibration of current timers should be made by examination of the welding current pattern. In the majority of cases of trouble shooting a welder, the maintenance man can go directly to examination of this pattern without a check of control panel output first. For this inspection, there are several ways of putting the secondary current signal on display on the scope. The method used depends upon the accuracy of wave shape desired. The writer lists here the known methods without discussing which is the most accurate. Richter[4] has described the torroid coil and integrating circuit detector. Another form of air-core transformer is a coil and integrating circuit as described by Matthews.[5] This coil is merely set in the throat of the welder with the axis of the coil perpendicular to the plane of the welder throat. Another method that has been used to obtain the welding current signal on the scope is to place the face of the scope within a few inches of the welding electrodes with the axis of the cathode-ray tube in the plane of the welder throat. Woodmancy[6] has described a method of putting a voltage of the welding circuit through an integrating circuit into the scope input. Regardless of how it is detected, the signal being discussed is the welding current signal. Such a signal is shown in Fig. 3. This is a full cycle of frequency converter welding current and is made up of two cool or interpulse times and two heat or pulse times. The two heat times are of opposite polarity as is characteristic of frequency converter welders. Each has three distinct peaks, or pips as we shall call them. These are the result of the power tubes, ignitrons, firing. An ignitron fires to cause each pip and in this case (Fig. 3) no ignitron has fired twice. This is a correct pattern for $^1/_{60}$ sec heat timer setting and $^1/_{60}$ sec cool timer setting. Hereafter, these time intervals shall be spoken of as cycles, meaning $^1/_{60}$ sec. The correct heat time can conveniently be determined by merely counting pips and dividing by three to convert to cycles. Cool or interpulse time cannot be conveniently determined on the scope. It is not necessary that it should be. Cool timer calibration is made on the control panel output signal or by other means. For the heat or pulse timer to be calibrated, it is necessary that the number

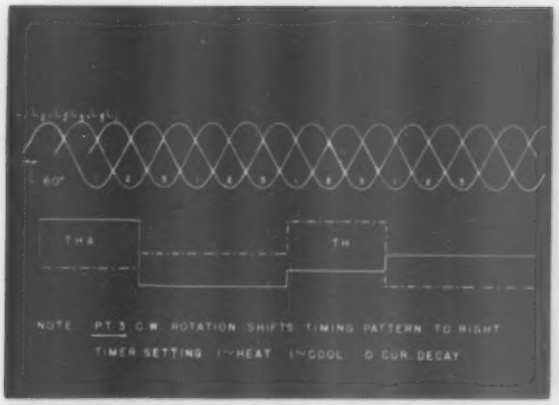

Fig. 4 Control thyratron a-c plate voltage and d-c grid voltage

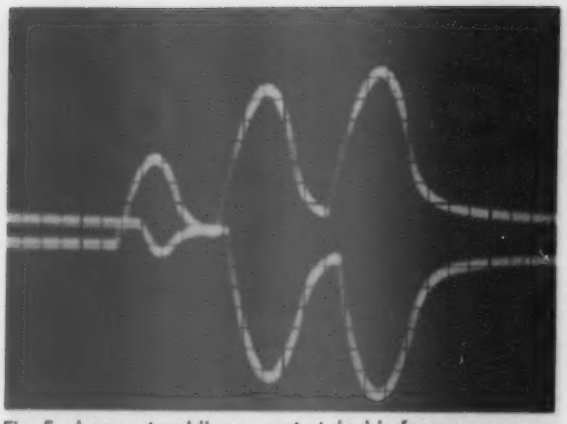

Fig. 5 Incorrect welding current at double frequency sweep

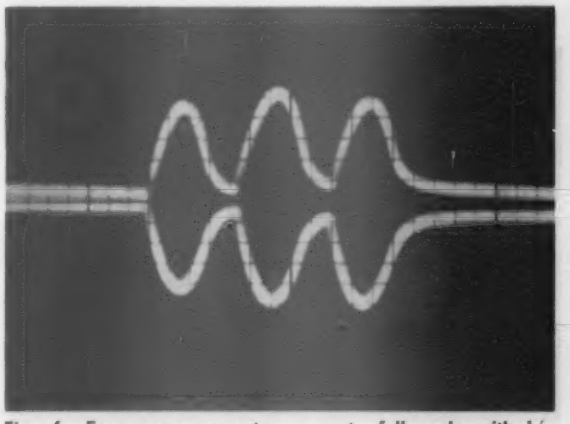

Fig. 6 Frequency converter current—full cycle with $^1/_{60}$ sec pulses—sweep frequency twice signal frequency

of cycles of time as shown by the scope agree with the dial setting of the timer. Long current impulses become difficult to read because of the crowding of the pips. At this time the direct writing magnetic oscillograph can be used to continue the calibration if it is necessary. The use of this instrument will be discussed later.

It has been observed by the author that current timing calibration needs to be checked with the welder in full operating condition. The reason for this is that timing is not always the same at all phase shift positions. The most common condition to occur is for an extra pip to appear as the phase shift is reduced; i.e., heat control is advanced. This need not occur and should be eliminated since it can be detrimental to short current time welding such as is used on aluminum or magnesium. It is caused by either improper adjustment of the welder for timing synchronization or inadequate timing calibration.

A study of Fig. 4 will show why the lack of timing synchronization will cause faulty weld current timing. This is a diagram of control thyratron plate voltage and grid voltage. The third factor in this study is the point on the a-c plate voltage at which the tube would fire according to the position of the phase shift control. When studying this diagram, Fig. 4, one must keep in mind the following: (1) that the plate voltage of the ignitron, controlled by the thyratron being considered, is in phase with plate voltage of the thyratron; (2) once an ignitron starts to conduct it cannot be stopped until its plate voltage is near zero. With variations of Fig. 4 showing the grid voltage phase shifted relative to plate voltage but still having the same frequency, it can be seen that this phase shift will cause undesirable results. Several things can happen. Among them are an extra $^1/_2$ cycle of current at high heat, an extra $^1/_2$ cycle of current at a low heat, unequal pulses such as shown by Fig. 5, and inability to obtain ignitron balance.

The oscillograms of Figs. 5 and 6 and others shown later are obtained with a simple technique. This consists of adjusting the sweep frequency to double the welding current frequency. For frequency converter welding current signals, this technique places the two pulses of opposite polarity opposite each other on the oscilloscope trace. This enables one to more easily compare the two pulses. When the scope is used to obtain ignitron balance this technique with the scope is required.

Another significant use of the scope is the attainment of ignitron balance on frequency converter welders as described by Woodmancy.[5] Briefly, the method consists of placing the welding current signal through an integrating circuit into the scope input and adjusting sweep frequency of the scope to double the welding current frequency. The welder is operated one phase at a time so that the current is that produced by one pair of inverse parallel connected ignitrons. By observing the double-frequency sweep signal on the scope, the internal ignitron balance control can be adjusted to the balanced condition. This is a timing phenomena so that only the time axis of the oscilloscope grid requires attention. Since this is the most precise coordinate on the oscilloscope grid, a fine adjustment can be achieved. The signal that should be obtained is that

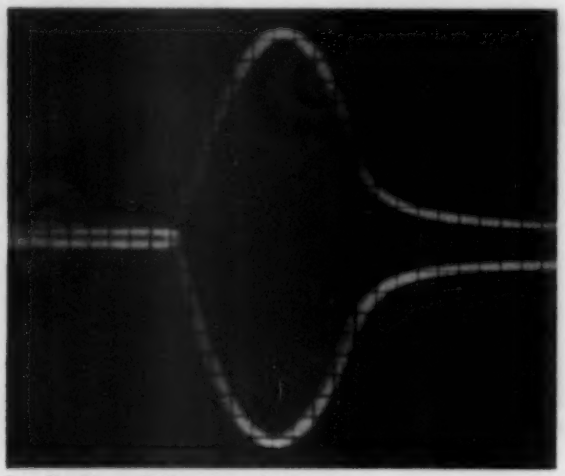

Fig. 7 Phase "A" ignitron balance

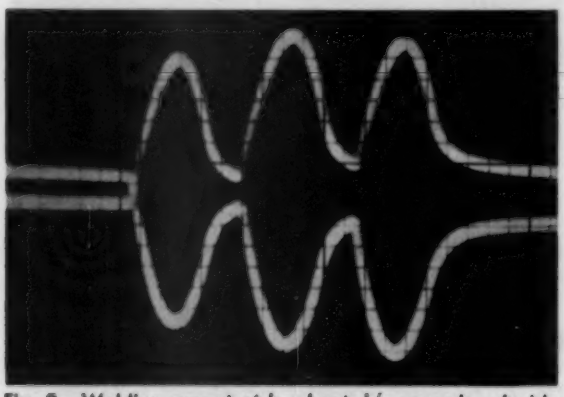

Fig. 8 Welding current at low heat, $^1/_{60}$ sec pulse, double frequency sweep of scope

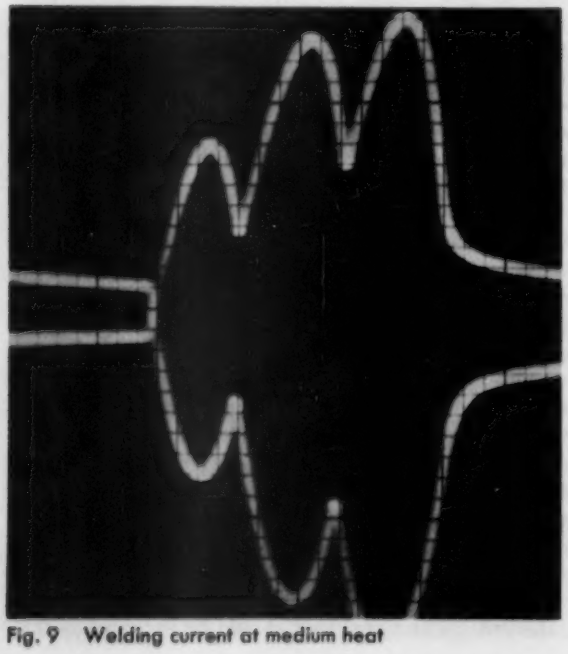

Fig. 9 Welding current at medium heat

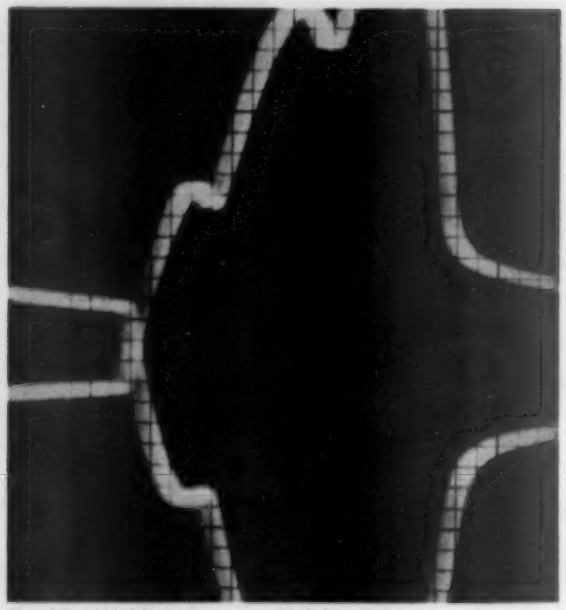

Fig. 10 Welding current at high heat

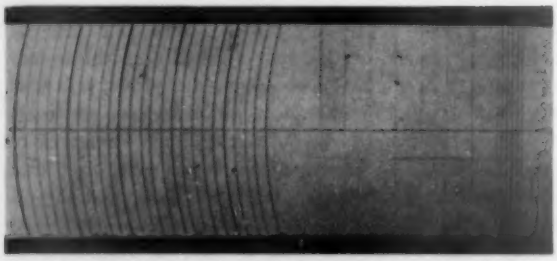

Fig. 11 Cycle ruler of acrylic in curvalinear coordinates

of Fig. 7. The signal showing an unbalance is very similar except that the intercepts on the time axis of the two halves of the signal are not at the same point. For frequency converter welders ignitron balance must be achieved for consistent welding.

Another use of the scope is examination of the response of the welder to advancement of the current magnitude control. The manner in which this is done will depend upon characteristics of the welder being checked. Regardless of what machine it is, though, it must be set up for continuous flow of welding current for the duration of the test at a frequency that can be read on the scope. Figures 8, 9 and 10, in order, show welding current at low, medium and high magnitude. This check can be made very quickly and indicates whether the control is smooth and whether the timing remains the same at all current magnitudes. A similar check can be made of post heat current magnitude control. Figures 8, 9 and 10 were obtained with a sweep frequency of the scope double the welding current frequency.

Use of Direct Writing Magnetic Oscillograph

Of the topics listed in the introduction, the following

are applicable in a discussion of the uses of direct writing magnetic oscillograph: (1) timing calibration, (2) welding current and pressure correlation, (3) weld pressure calibration and (4) miscellaneous.

Accessories to be used with the oscillograph have been previously described. The required ones are pressure transducer and weld current detector.

Timing calibration of welding current dials can be conducted rapidly with the oscillograph. The welding current signal is recorded and the time interval determined from the oscillogram. The entire calibration of all significant timers can be carried out with the oscillograph or the oscillograph used where the scope becomes inconvenient. The advantage of making the complete calibration with the oscillograph is that a permanent record results which is used for later reference. The calibration of the dials on the welder can be either in cycles ($^1/_{60}$ sec) or in milliseconds. Because of the rapidity with which this calibration can be carried out, the operation should be done periodically as a quality control measure. With the frequency converter type of welder, correct timing of the welding current is a very important variable effecting welding consistency over a long period of time.

One procedure for carrying out timing calibration of frequency converter welders is given here. First, the oscillograph is connected to the current detecting circuit after the proper warm-up period. Amplifier gain is adjusted so that the recorded signal can be read easily. Welder controls are set to produce several cycles of welding current at the highest frequency possible. After checking the pulses of opposite polarity at this frequency, the next combination of dial settings is set and the procedure repeated. By operating the on-off controls of the welder and instrument simultaneously, a minimum of chart paper is used. Examination of the recording will show the time interval for each position of the timers. A measuring ruler marked in cycle intervals with the same coordinate system as the chart paper is very convenient for reading oscillograms. Figure 11 is such a ruler made of transparent acrylic. Figures 12, 13 and 14 are representative oscillograms.

Another important item conveniently investigated with an oscillograph is correlation of welding current and welding pressure. The simultaneous recording of these with the two-channel oscillograph makes this possible. An oscillogram for one manufacturer's frequency converter type welder is shown in Fig. 15.

The main item of information regarding correlation of current and pressure is the time relationship of the two variables. This time interval is forge delay for a variable or two-stage pressure cycle. The timer for this is not calibrated as are the current timers. For a given welder, the oscillograph is used to establish the minimum and maximum of the timer. These are established by the circuit design of the welder. Once a welder has had machine acceptance tests made for the thickest and thinnest materials to be welded which require a forge pressure, the minimum and maximum of the forge delay timer become relatively fixed. There

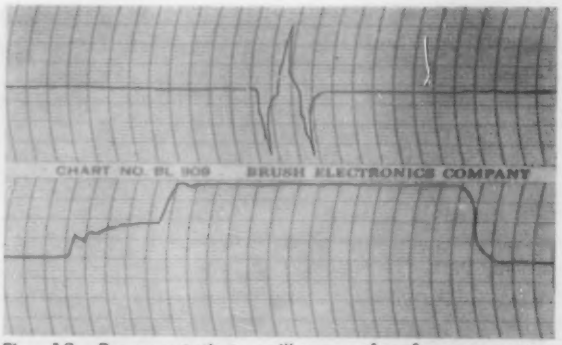

Fig. 12 Representative oscillogram for frequency converter welder—three-phase multiple impulse current and constant pressure

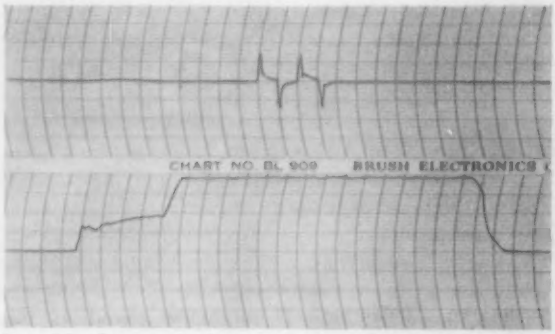

Fig. 13 Representative oscillogram for frequency converter welder—single-phase multiple impulse current and constant pressure

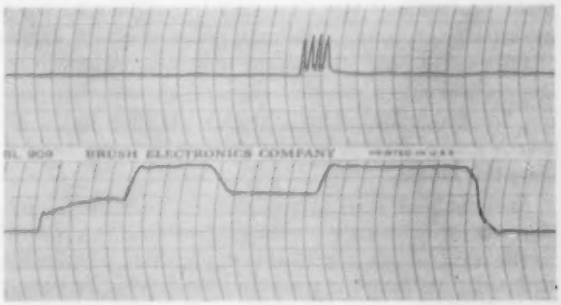

Fig. 14 Representative oscillogram for frequency converter welder—single-phase single-impulse current and variable pressure

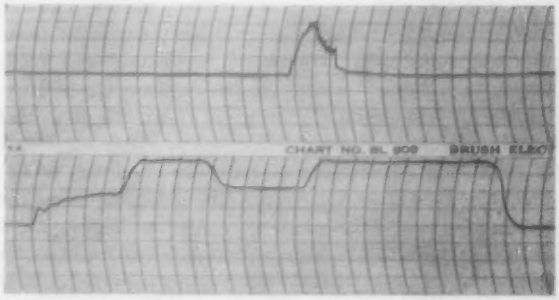

Fig. 15 Representative oscillogram for frequency converter welder typical for aluminum spot welding

is no exact time interval that has to be maintained since the operation of the equipment does not require it. However, once a machine is qualified for production use, the minimum forge delay should not be longer than the minimum delay at the time of acceptance tests. Neither should the range of the timer become less. Maintenance work should be performed if these two requirements are not met.

Further information that can be obtained with the oscillograph is information regarding welding pressure. A constant-pressure cycle does not require an oscillogram but a variable or two-stage pressure cycle requires an oscillogram to ascertain all of its characteristics. The pressure transducer described previously enables such an oscillogram to be made. This oscillogram will show information as to pressure magnitude at each instant of time during the pressure cycle, the rate at which forge pressure is applied, time duration of each portion of the cycle and the ratio of forge pressure to weld pressure.

For pressure magnitude measurement, the system must be calibrated. This can be done easily for a linear transducer such as the one shown by applying a known load to the lower arm of the welder and adjusting the gain settings of the amplifier for the desired deflection. The known load divided by the chart deflection is the calibration factor in pounds electrode force per unit of oscillograph deflection. It might be asked at this point: Why have an oscillogram to measure welding pressure when there are pressure gages on the welder? The answer is that a welder pressure system does not always behave the same in dynamic operation as in static operation. Also, it is easy to overlook on some pressure systems that the unit pressure in a pressure chamber is not the same as the unit pressure shown on the corresponding pressure gage. The variation may not be of significance to a production shop but a research group striving for accuracy of data has to consider this factor.

An item that is of utmost concern to a production shop doing light alloy welding using forging pressure is the rate of forge pressure application. Difficulty with weld cracking and porosity can often be attributed to a slow rate of forge. Even on machines designed with a low inertia head, there are certain factors of operation and maintenance of the welder that can defeat the purpose of the design. Namely, these are electro-valve adjustment, lubrication, grease seal adjustments and working stroke adjustment. On most welders, forging is achieved by exhausting a back pressure; therefore a rapid forge requires a rapid exhaust. A fast action electro-valve is important to this rapid exhaust. Another adjustment effecting speed of exhaust is tip spacing in stand-by condition of the welder. This tip-spacing should be nearly equal to the working stroke of the welder. A few oscillograms will show the variation. Lubrication policies for welders should be well established to provide adequate lubrication for production use of welders. Grease seals between working parts of the welding head should be set no tighter than necessary for an effective seal. A seal can be set so tight on some welders that the low inertia design is defeated.

The uses of an oscillograph are not confined to spot welders alone. They can be used on seam welders for most of the uses mentioned for spot welders. In addition, the proper use of a two-channel oscillograph can show motor braking time. Standards can then be set up for a periodic maintenance check.

No discussion of the use of oscillographs would be complete without mention of the value of oscillograms in instruction of various personnel connected with a spot-welding shop or maintenance department. The oscillogram makes possible a visual presentation of welder operating characteristics that clarifies as only pictures can do. For the highly versatile welders such as the frequency converter, the many different operating conditions can be shown. Examples of correct and incorrect operation can be obtained and made available for future reference.

Closely related to the use of the oscillograph for educational purposes is its use as a tool to personnel who have to establish a machine setting to pass requirements of process standards or specifications. Some of the trial and error of the procedure can be eliminated by intelligent use of the oscillograph. In addition, an oscillogram is available that tells at a glance the type of operation the choice of machine settings has given. This oscillogram can be filed for future reference.

Conclusion

It is hoped that this paper has demonstrated that the cathode-ray oscilloscope and direct writing magnetic oscillograph are useful and necessary tools for welder maintenance under a high requirement quality control program. The author realizes that many of the uses listed for these instruments are not new to personnel in companies that have been and still are leaders in the use of resistance welding. However, since this information has not been previously published in a detailed manner, it is hoped that this paper has added to the record of our knowledge of welding and in so doing will stimulate new thinking and further application of instruments to resistance welding.

Acknowledgment

The author wishes to thank his associates at Boeing Airplane Co. and the Sciaky Brothers Service Dept. for their help and cooperation.

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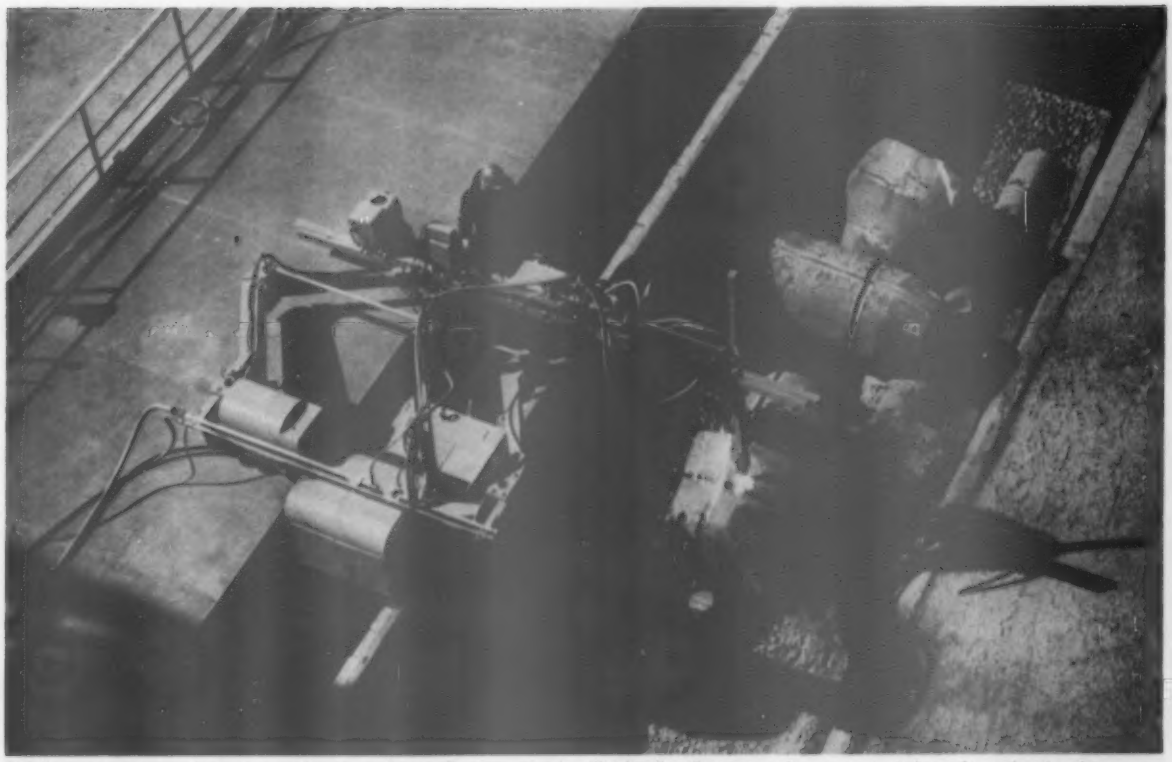

This heavy scrap cutting operation in a large Eastern steel mill ideally illustrates the six principles of mechanized oxygen cutting

MECHANIZATION APPLIED TO OXYGEN CUTTING

Modern cutting machines can be provided with automation in material handling and with electrical controls for routine high quantity production of precision work

BY R. L. DEILY

Flexibility in use has been the outstanding characteristic of oxygen cutting since its beginning in the early 1900's. In present-day machines for oxygen cutting, the design engineer has retained much of this flexibility, while at the same time providing the steel industry with oxygen-cutting machines of great versatility and adaptability. These cutting machines can now be, and in many cases are, provided with automation in material handling and with electrical controls for routine high-quantity production of precision work. In brief, oxygen-cutting machines should now be thought of for the same work as conventional mechanical machine tools.

This was not always so. While the development of oxygen-cutting machines has been under way almost since the cutting torch was introduced in the early 1900's, the oxygen-cutting process itself was sufficiently impressive in that period. Oxygen cutting could readily be done (and this is still true) by putting a man on one end of a torch and a job on the other end. (In-

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Presented at the AWS National Fall Meeting held in Chicago, Nov. 1–5, 1954.

Fig. 1 Twisted steel on Pier 14, New York, after $1,000,000 fire in 1910

Fig. 2 Two oxygen torches and 18 men replaced 35 iron cutters on this scrapping job

cidentally, the author is using oxygen cutting to mean both severing and scarfing operations.) An early example of cutting illustrates its ease of use and its inherent speed.

In 1910 a $1,000,000 fire destroyed Pier No. 14 in New York, leaving a twisted ruin of steel members on a still usable base. H. A. Hitners Sons Co. took over the dismantling job of the wrecked steel structure (Fig. 1). They were under contract to clean up the pier in 30 days, after which a $300-a-day performance fee would apply, and intended to use 30 to 35 iron cutters (mechanical chipping) on the work with the expectation of six to seven weeks on the job. Using the then new oxygen torches (Fig. 2) it was found that 18 men and two torches cleaned up the job in 23 days. Thus, even in its earliest applications, oxygen cutting produced labor-saving results with a minimum of fuss.

With such inherent advantages, it is not surprising that complete mechanization of the process did not appear as soon as it otherwise might have. While the early torches were used on simple mechanical guiding devices, detailed engineering development proceeded somewhat slowly. It took the urgent demands of World War II to bring about the maturing of oxygen cutting to standard production work with completely mechanized cutting machines. Since World War II the application of newly developed controls to such machines has placed oxygen cutting in the machine tool class, with certain important advantages peculiar to the process.

Six Essential Factors in Mechanized Oxygen Cutting

These advantages stem from the flexibility inherent in oxygen cutting. It may be stated that designers of such machines have always been faced with the problem of retaining this flexibility, while they were obtaining the advantages of special-purpose machine tools. Before describing the various types of mechanized oxygen cutting machines, it is instructive to examine their basic characteristics.

The essential factors in any completely mechanized oxygen cutting are:

1. A materials handling system.
2. A machine designed for the job.
3. An operator's station with complete electrical controls.
4. A gas system engineered for adequate quantities of oxygen and fuel gas.
5. A known cutting process.
6. Trained personnel.

Given a combination of these factors, it is important to note that the job at hand can be done with complete predictability of results. As is well known, there are

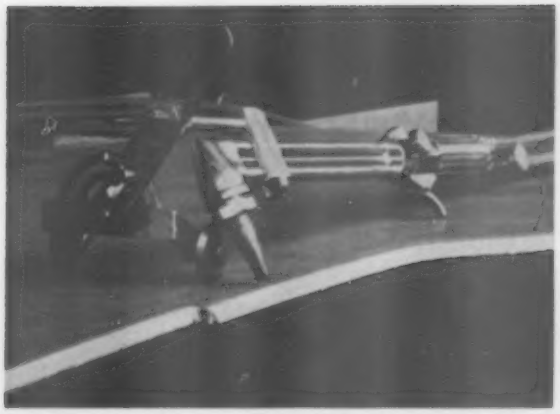


Fig. 3 The simplest type of mechanized oxygen cutting

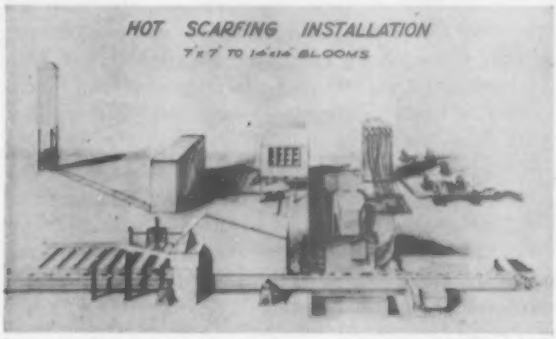


Fig. 4 This complex scarfing machine lay-out ideally illustrates the application of the six basic factors of mechanized oxygen cutting

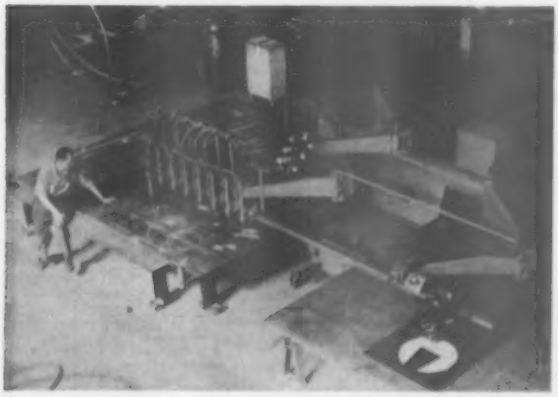


Fig. 5 All control elements of current precision oxygen cutting machines are electrically operated so that the operation can work from a single station through push-buttons

thousands of fabricating shops, steel mills and other users who are depending on oxygen cutting for day-by-day production.

Which of these six essential factors will be designed into a single machine depends on the job to be done. Inevitably, the more completely they are all engineered into a single setup, the more the flexibility of the oxygen-cutting process is lost in the interest of higher production and lower costs. In any event, the oxygen industry now supplies equipment from the simplest pair of wheels (Fig. 3) on a torch to the most complex single-purpose machine that can be designed with present knowledge.

There are numerous oxygen-cutting units that would illustrate such complex machines, of which the scarfing machine shown in Fig. 4 is an ideal example.

An outstanding installation of an oxygen-cutting machine involving all of the essential factors was described in the September 1945 WELDING JOURNAL by E. E. Hart of John Inglis Co., Ltd., Toronto, Ont., Canada, in an article entitled "A Machine for Production-Flame Cutting of Small Shapes." This company was making pistol blanks at a high production rate. After the bar stock was charged on this 8-torch machine, all operations were in sequence. That is, the locating, cutting, ejection of cut components, positioning of the bars for the next cut, and the conveying of the cut components to a point where they may be shoveled into skids for transportation to the next operation were mechanically carried out.

The cost of this mechanized cutting machine was $14,000 plus run-in costs of $6000. Savings of $109,000 were realized in the first six months of operation, as compared to the cost of forgings for the pistol blanks being made. Production ran at 55 to 60% of the theoretical figure derived by totaling cutting time, template tracer removing time and stock ejection and loading time. For those familiar with machine shop operation, these figures will have a familiar ring.

Oxygen Cutting in Steel Fabricating

In the field of precision cutting for steel fabrication, the modern pantograph cutting machine (Fig. 5) has relatively high flexibility with extreme accuracy of cutting results. Current design of such units have gas systems with solenoid controlled valves (Fig. 6), electrically operated torches (Fig. 7), the electronic eye

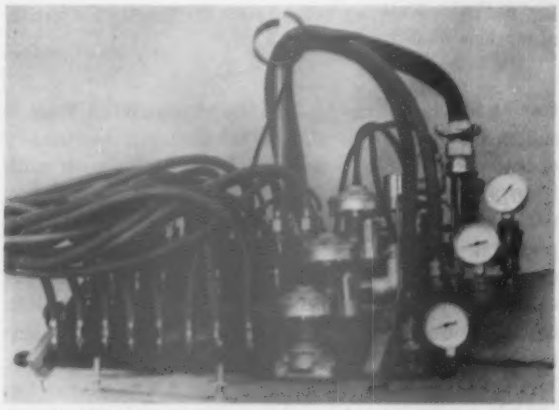


Fig. 6 Electric solenoid valves controlling preheat and cutting gases of machine illustrated by Fig. 5

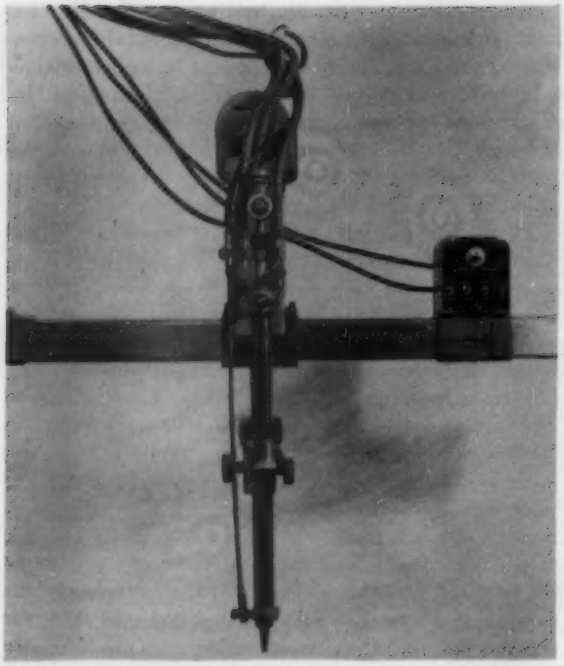


Fig. 7 Electrically operated torches of machine illustrated by Fig. 5

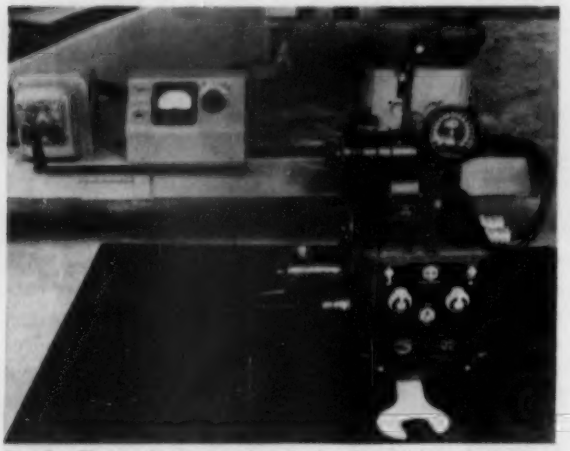


Fig. 8 Electronic eye tracing device for guiding the torches of machine illustrated by Fig. 5

tracing device (Fig. 8), all being controlled from a single station. With all control elements electrically operated, it is now possible for the operator to work from a single position on a push button basis. The nerve-racking business of manually following a template, all the time being concerned about turning on and off cutting oxygen, is now done electrically for the operator. As a result, he can concentrate his attention on the over-all progress of the job. He, therefore, does better and more precise work.

A very excellent description of the advantages of the electric eye tracer used with precision-cutting machines is given in a paper by H. B. Cary (THE WELDING JOURNAL, October 1953, page 957). Mr. Cary describes great savings in steel and man-hours throughout his weldment shop based on the use of complex templates with the electric eye tracer. As an interesting sidelight, nesting of templates on the same plate by Mr. Cary's company results on one pattern in 8 hr of continuous burning on a single $^1/_2$-in. thick plate.

In summary, the precision-cutting machine and electric tracer illustrated herein have made oxygen cutting an indispensable tool in fabricating steel.

Steel Mill Mechanized Oxygen Cutting

A discussion of mechanized oxygen cutting would not be complete without the interesting applications directly used in steel production. Here the scarfing machine is important, both for increased production of steel and because, as already described, it illustrates the six basic design factors of oxygen cutting.

The scarfing machine is typical of a mechanized operation which consequently loses some of the flexibility of the oxygen-cutting process in order to get high production. An interesting intermediate step of mechanizing a hand scarfing operation was described by A. B. Glossbrenner of the Timken Roller Bearing Co., in a paper "Hot Skin Scarfing with a Mechanical Bloom Turner," presented at the 1954 Annual Convention of the AISE. By installing mechanical bloom turners and lift trucks for moving steel, the Timken Co. reduced man power by about 50% and increased production by two-thirds on a hand-scarfing bed.

Hot Cutting

In the field of hot cutting, several outstanding machines have been either designed or designed and manufactured in the past few years. All such installations again required the six essential factors but, in addition, called for the determination of extensive process data. The art of oxygen cutting steel in normal thicknesses and at normal temperatures has been well known for years. However, predictable cuts on hot steel were

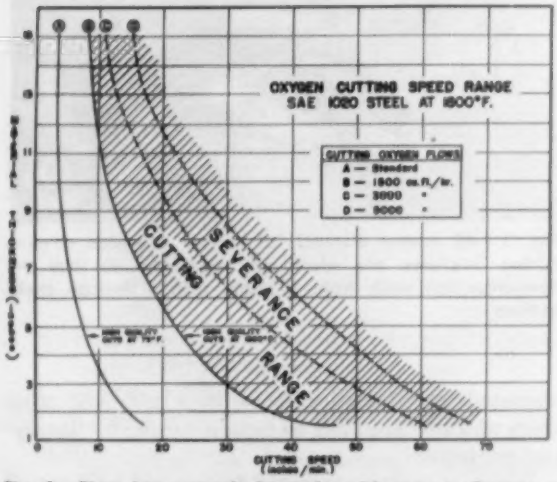


Fig. 9 The above graph shows the wide range of oxygen cutting speeds that can be obtained at 1800° F

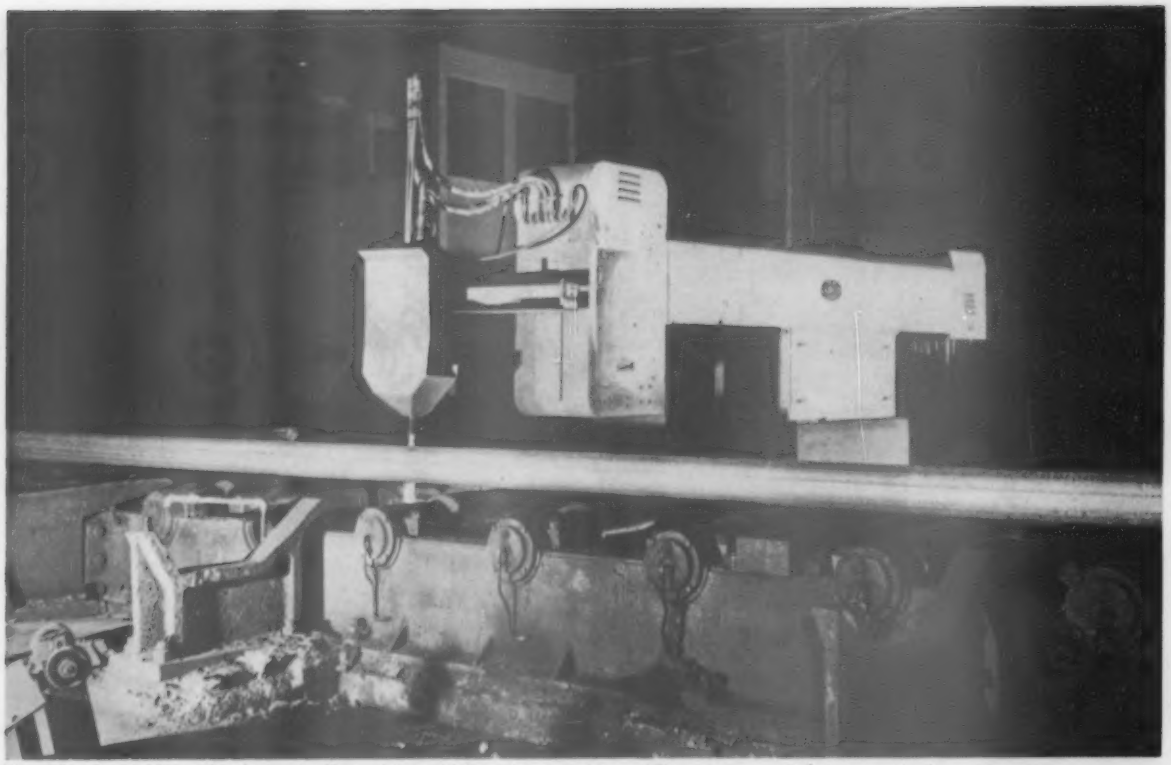


Fig. 10 Front view of a hot cut-off machine which makes consistent 17-sec cuts on $8^1/_2$-in. rounds shown

possible only after extensive laboratory work. A detailed description of some of these data is given by J. F. Kiernan and J. S. Sohn, "Oxygen Cutting of Steel and Elevated Temperatures," THE WELDING JOURNAL, April 1947. We have learned from these tests and from operating experience that:

1. Quality cuts can be produced on steels at elevated temperatures at from two to three times the cutting speeds on cold material.

2. Consistent severance cuts on steel at elevated temperatures can be made at speeds up to seven times those on cold material.

The general relationship between material thickness and cutting speeds are given in Fig. 9. The graph shows oxygen cutting speeds at 1800° F, about the usual temperature on steel rolling mills. Curve *A* showing cutting speeds at room temperature is shown for reference. Curve *B* shows quality cutting speeds at 1800° F, while curves *C* and *D* show the great increases in cutting speed that are possible with higher oxygen flows. These increased speeds are obtained at some sacrifice of cut quality, but since most steel severed during a rolling operation will be subsequently processed, a lower quality cut is no more detrimental than a comparable shear drag.

Hot Bloom Cut-Off Installations

Present-day design, using such hot cutting data and the other five factors, is shown by the recent installation of a hot cut-off machine in a large Eastern steel mill

Fig. 11 Rear view of a hot cut-off machine which moves the oxygen cutting torch across the roller line with an 80-in. stroke

(Fig. 10). The problem here is to cut long multiples of $8^1/_2$-in. round blooms to 30-ft lengths on the run-out table from a 30-in. mill without disturbing the rolling mill cycle. Twenty-five seconds are allowed for each cut. This requirement has been readily met, since trial cuts shortly after the machine was installed showed that it is possible to make consistent cuts in as little as 17 sec. Figure 11 also shows the rugged design of the unit. All moving parts are so thoroughly protected by shields or covers that a first glance conveys the impression of a completely stationary mechanism. Actually, the whole upper half of the machine, from the torch back to the service hoses, is a moving ram which has an

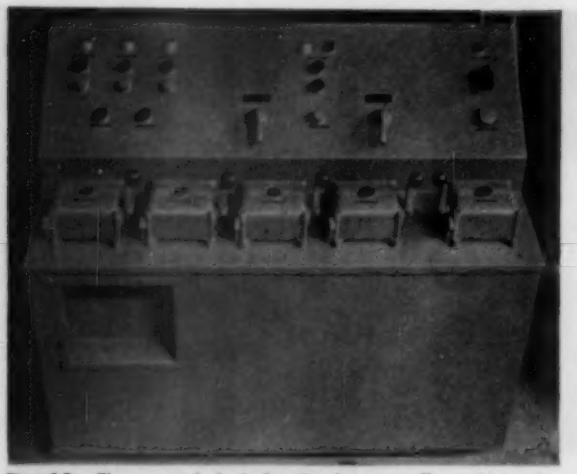


Fig. 12 The control desk for the hot cut-off machine giving the operator complete control of all necessary machine and torch movements

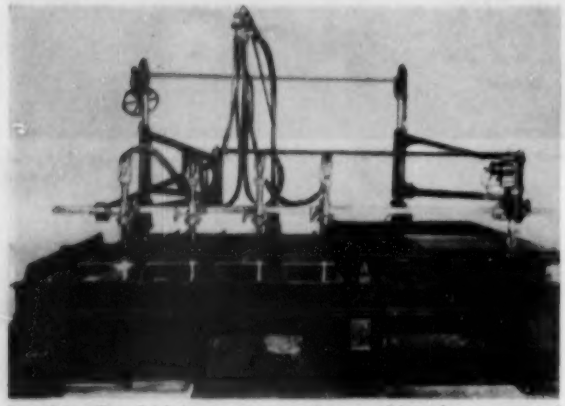


Fig. 13 The 1924 precision cutting machine shows manual tracing along with early manifolding of the gas system

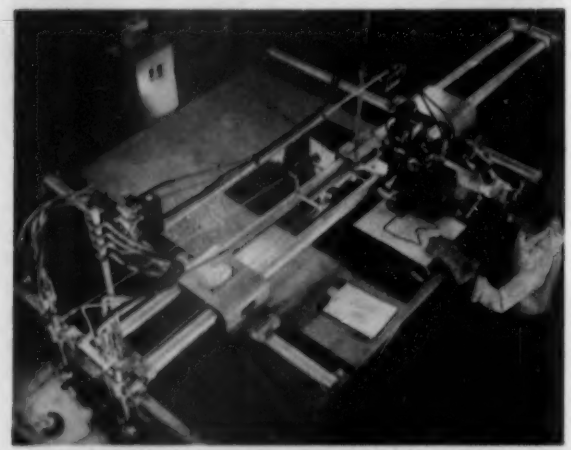


Fig. 14 This 1954 precision cutting machine shows current design resulting in complete control of the cutting from an operator's station

80-in. stroke. This stroke is sufficient to move the torch at cutting speeds completely across the roller table so that blooms of any size can be cut.

The machine operator stands in the pulpit shown in the background in Fig. 10 with the following controls under his direction:

1. Roller table for positioning bloom under torch.
2. Raise and lower torch (see Fig. 12).
3. Forward and reverse torch (see Fig. 12).
4. Preheat gases and cutting oxygen (see Fig. 12).

All parts of the cutting machine subject to excessive radiant heat, specifically the torch and the large elevating head at the front of the ram, are water cooled. Operating parts of the machine are accessible through doors for routine maintenance. In addition, a central lubrication system is provided so that proper care of the machine is easier. Since there are no heavy mechanical loads on any part of the machine, it has been found to give almost 100% uninterrupted service.

The working part of the machine is the torch and tip, neither of which is subject to any mechanical load. Since the cutting tip clearance above the steel is from $1^1/_2$ to 2 in., there is very little fouling of the tip from flying scale. A cutting tip can be changed in 10 min if it should accidentally become damaged.

The outstanding advantage of oxygen hot cut-off is this almost 100% availability of the tool. With a minor stock of maintenance part and a minimum of routine maintenance, such a cut-off machine is available at all times for work so long as there is an adequate supply of oxygen and fuel gas.

One further outstanding application of mechanized oxygen cutting to direct steel mill production must be mentioned. The Koppers Co. has recently installed at the Atlas Steel Co., Ltd., a continuous steel casting machine. This unit is now producing approximately 50 tons per hour of 5- x 20-in. steel bar directly from molten metal. The process was described in detail at the 1954 Annual AISE Convention in Cleveland. It is of interest that the continuous casting of these steel billets depends on an oxygen powder cut-off unit for its successful operation.

Further Illustration of the Six Factors

In further illustration of the six factors, two old and new designs of mechanized oxygen cutting are instructive. Figures 13 and 14 show precision-cutting machines of 1924 and 1954 dates, respectively. It will be noted that the 1924 design included a manual tracer as well as a common gas system. With this unit, an operator could produce precise cutting work, although the mechanics of the operation required considerable activity on his part. The 1954 machine on the other hand, shows current design concept of having all controls at the operator's finger tips, including gas controls, raising and lowering of torches and the electronic tracer. The resulting compactness of modern cutting machine design is apparent.

Present-day oxygen cutting of heavy scrap in steel mills is a vital factor in maintaining production sched-

Fig. 15 Method of cutting and lancing heavy steel mill scrap as practiced approximately 10 years ago

ules and reducing costs. Such heavy cutting required development of a successful process, after which the operation could be mechanized. Figure 15 shows the method of cutting and lancing heavy scrap as it was done approximately 10 years ago. It is of interest that the operator is having difficulty with the cut, as was frequently the case at that time. It should also be noted that two men are performing this operation, and that the lanced scrap will have to be subsequently handled for blasting.

In contrast to this, the lead illustration shows a mechanized oxygen cutting setup for preparing the same heavy scrap on a one-man basis. This installation illustrates all the six factors necessary:

1. Materials handling by rail car to and from machine.
2. Machine designed for the job.
3. Operator's station shown in Fig. 16.
4. A complete gas system.
5. A known cutting process, which, as previously stated, had to be developed before mechanization was possible.
6. Trained personnel, fully aware of cutting process requirements and safe practices.

The author believes it will be worth while for both users and designers to examine any particular oxygen cutting problem in the light of the six factors discussed. By so doing, the user may be able to improve his setup in any or all of the factors listed. He will then come closer to reaching the great American goal of more production with fewer rejects and at lower costs.

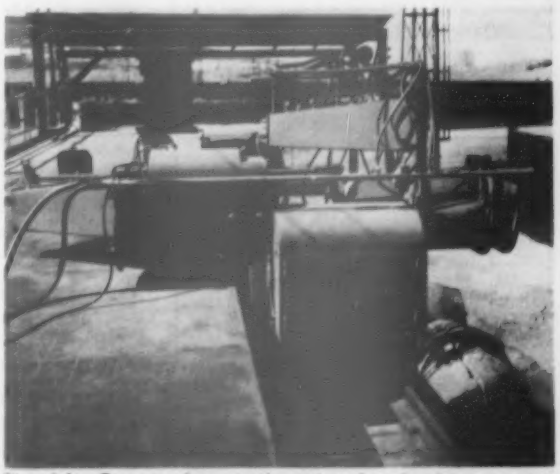


Fig. 16 Operator's control station for the heavy scrap cutting illustrated in lead illustration

IRON-POWDER ELECTRODES —A PROGRESS REPORT

A review of the first year's history of iron-powder electrodes and a summary of the experience that has been gained since their introduction

BY JERRY HINKEL

Since this is to be a progress report, we will not be presenting highly technical information but instead will discuss what has happened, what is happening and to some extent what we expect will happen with iron-powder electrodes.

Iron-powder electrodes made by American electrode manufacturers were introduced a little over a year ago. From the first, these products represented a notable contribution to the arc welding industry. Their advantages have been obvious.

Because they represent a fairly radical departure from conventional electrodes, their introduction has presented some unusual problems both to the manufacturer and to the user. Fortunately, it can be reported, most of these problems have been met successfully and answers worked out to the best interests of all concerned.

One year is hardly sufficient time to investigate all of the possibilities of this development and to resolve all of the special problems. However, considerable experience has been gained, and it has been a very interesting and productive period for all concerned.

Jerry Hinkel, Application Engineer, Lincoln Electric Co., Cleveland Ohio

Presented at the AWS National Fall Meeting held in Chicago, Ill., Nov. 1–5, 1954.

IRON POWDER ELECTRODES

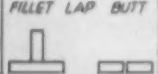
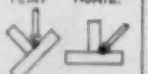
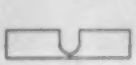
TYPE	JOINTS	POSITION	TENTATIVE CLASSIFICATION	PRESENT CLASS.
TITANIA	FILLET LAP BUTT 	FLAT VERT. O.H.	E-6014	——
TITANIA	FILLET	FLAT HORIZ. 	E-6024	E-6012 (MODIFIED) & E-7020
IRON OXIDE	DEEP GROOVE BUTT 	FLAT	E-6027	E-6020

Fig. 1 Types of iron-powder electrodes

Types Available

At the present time, all of the newly developed iron-powder electrodes may be separated into four tentative classifications (see Fig. 1):

1. Iron powder—titania, all position. These electrodes may be most aptly described by saying that they are very similar to E-6013 electrodes with some of inherent advantages of an iron powder type. The AMERICAN WELDING SOCIETY has tentatively reserved classification No. E-6014 to cover this type.

2. Iron powder—titania, flat and horizontal fillets. These electrodes are in many respects similar to E-6012 type but have significantly higher deposition rate. The AMERICAN WELDING SOCIETY has tentatively reserved classification No. E-6024 to apply to this type.

3. Iron powder—iron oxide, flat and horizontal fillets. These electrodes are very similar to conventional E-6020 electrodes except that they have significantly higher deposition rate. The AMERICAN WELDING SOCIETY has tentatively reserved classification No. E-6027 to apply to this type.

Since this report was written, at least one low-hydrogen iron-powder electrode has been introduced, but this can hardly be considered as being past the field-test stage. No provision has been made as yet by the AMERICAN WELDING SOCIETY to provide an electrode classification number for this type.

It should be noted that the AWS numbers given are not official but have been reserved for these products pending approval of the proposed AWS iron-powder electrode specifications. It is expected that these numbers will be official very soon.

In the absence of an AWS electrode specification covering iron-powder electrodes, some confusion exists in type classifications currently used to refer to these electrodes. The iron oxide type has been the least

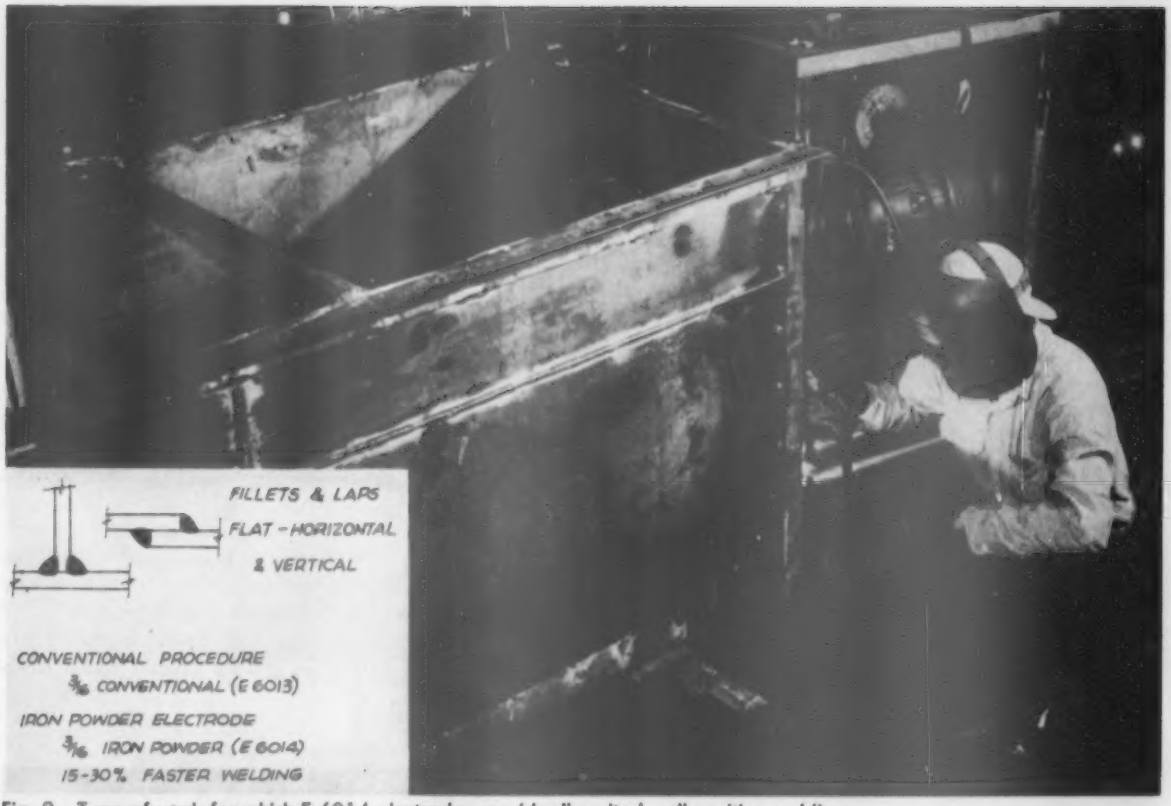


Fig. 2 Type of work for which E-6014 electrodes are ideally suited: all position welding

affected since its properties and usability characteristics conform directly to E-6020 requirements. But in the case of E-6014 and E-6024 types, any attempt to classify these products according to presently recognized AWS type numbers requires either a modification of the test procedure or some compromise in the interpretation of the specifications. This is the situation which has led to the present claim of "E-6012 modified" for electrodes which will eventually be classified as E-6024. The significance of the term "E-6012 modified" has been to imply that these products will meet all of the physical property requirements of E-6012 type except that they are suitable only for downhand welding.

In some cases the unfamiliar marking "E-6012 modified" has been sufficient to prohibit the use of these products on applications for which conventional E-6012 electrodes are considered acceptable. Many of these applications have been flat position welding, and since that is the only significance of the term "modified," it is regrettable that this misunderstanding has not been more completely reconciled.

Because of such misunderstandings, it is important to all concerned that an appropriate AWS iron-powder electrode specification be approved and made official as soon as possible.

For simplification, all references to these products in this report will be made on the basis of the tentative AWS numbers.

Relative Popularity

No reliable figures are available as yet as to relative popularity of types. However, it is quite apparent that the E-6024 type enjoys the greatest popularity at this time. Some of this popularity can no doubt be attributed to the fact that this type was the first to be introduced on a large scale. Notwithstanding this advantage, there is every reason to believe that this type will continue to be the most popular. Of the three types available, E-6024 electrodes offer the greatest and the most apparent advantages on the largest percentage of applications.

E-6027 type electrodes have been reasonably successful in replacing conventional E-6020 electrodes on many applications. But as yet they have not made the impressive strides of the E-6024 type. While it is quite possible that E-6020 electrodes may eventually be completely replaced by iron-powder electrodes, it is understandable that this will require a fairly long period of time.

While iron-powder electrodes have better operating characteristics than conventional E-6020 electrodes, these differences are not as spectacular as the differences between E-6012 and E-6024.

Since many of the applications for which E-6027 electrodes are best suited are, of necessity, code work, it will require varying degrees of preliminary testing on the part of the user to ascertain the product's suit-

ability for the job. Naturally the conventional electrode presently being used has satisfied similar test requirements, and the user is confident that it will continue to do so. In many cases the necessity of satisfying test requirements on a new and relatively untried product has been sufficient to discourage its use even though it has other obvious advantages.

Activity in the E-6014 type has been relatively limited, and only a few products of this type are available at this time. Since the inherent features that have come to be associated with iron-powder electrodes are inconsistent with the characteristics of electrode operation required to gain all-position use, this type offers some special problems not encountered in the other two types. Further development of this type can, however, be expected.

All-Position Iron-Powder Electrodes—E-6014

The electrode designer has been given a complicated assignment in the design of an all-position iron-powder electrode. In the first place, the name itself implies many entirely different things to different people. The pipe welding contractor sees it as a product suitable for welding pipe. The general construction worker imagines that it will be suitable for heavy construction work involving all types of welds in all positions. Some light fabricators expect it to be suitable for welding sheet metal, and this would naturally imply good vertical down operation. In addition to these complications, it is generally assumed that it should have a very high deposition rate and that the weld appearance standards should be comparable to E-6024 and E-6027 types.

The designer will tell us that it is virtually impossible to meet all of these requirements in a single electrode. In consideration of his problem, it should be noted that these varied applications are at present being handled with several different types of electrodes.

Lower Deposition Rate of All-Position Electrodes

One of the first concessions which has been made to gain all-position, or nearly all-position, welding characteristics is a reduction in deposition rate. Welds made in the vertical position, welding from bottom to top, offer a good illustration of why this is necessary. Under this condition there is a very definite limitation on the size of molten pool which can be successfully maintained. As the deposition rate is increased, the size of the molten pool is also increased, and this acts as an effective barrier in getting greater speed when

HORIZONTAL & FLAT FILLETS
3/4" PLATE SAE 1020
1/4" TO 3/4" FILLETS
OLD PROCEDURE
1/4" E 6012 —— 57 HOURS
NEW PROCEDURE SAVINGS 43%
3/16" IRON POWDER —— 33 HOURS

Fig. 3 Type of work for which E-6024 electrodes are ideally suited: downhand fillets

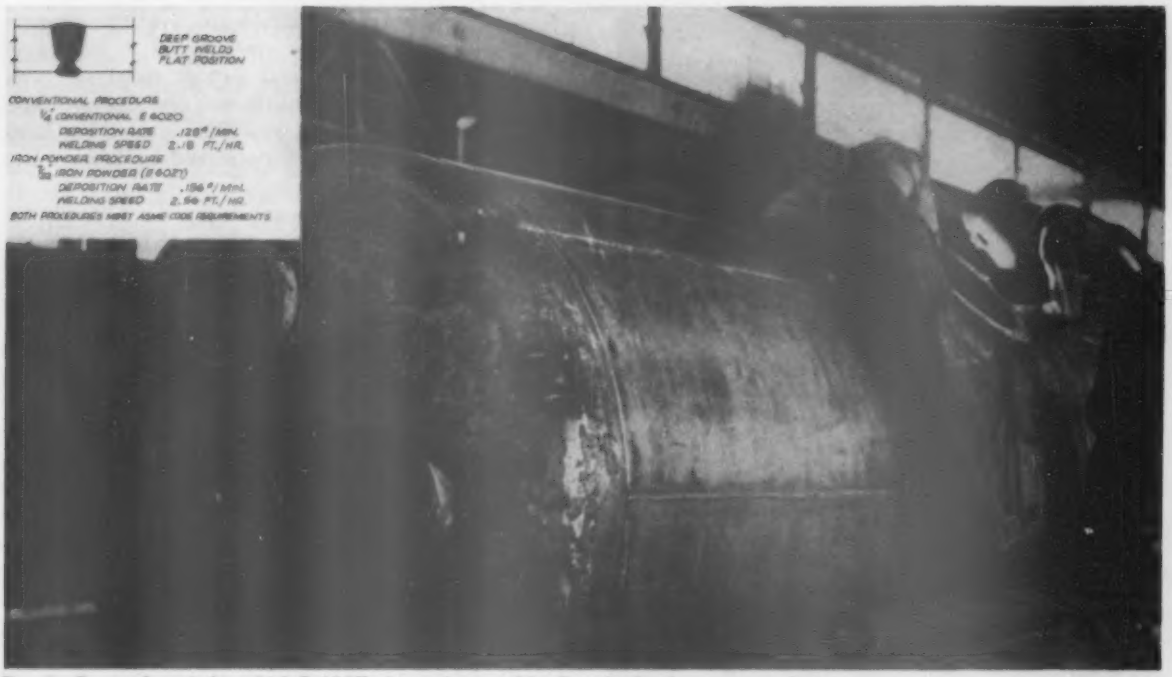


Fig. 4 Type of work for which E-6027 electrodes are ideally suited: deep groove butts

welding in this position. The same condition applies in the overhead or horizontal position but to a somewhat lesser degree.

At the present time the few all-position electrodes which are available could probably be best described by saying they are greatly improved E-6013 type with iron powder added for higher speed. They do not offer the complete versatility of an E-6010 electrode, nor will they duplicate the high deposition rate of E-6024 and E-6027 types. Instead, they represent a reasonable compromise of these variations, and the result is a product which has operating characteristics equal to or better than E-6013 electrodes and welding speeds equal to or better than E-6012 type. In their present state of development, it is not likely that the pipe welding contractors' interests will be served, nor is it likely that these products will have any great advantage for sheet metal welding. This is not to say that iron-powder electrodes would not be suitable for this type of welding but rather that because of the particular nature of work, they are not likely to be any faster or more economical than a conventional electrode.

It would seem that all-position iron-powder electrodes, because of the compromise design, would have their greatest acceptance in that large field of random applications currently being welded with E-6013 electrodes (see Fig. 2). Such a replacement would be at no sacrifice in welding characteristics and would have the advantage of considerably higher speed over E-6013.

Iron-Oxide Type Electrodes—E-6027

The E-6024 type electrodes were discussed in detail in a paper at the 1954 Spring Meeting of the AWS, and, therefore, no further report need be made here (see Fig. 3).* The E-6027 type electrodes, however, have been introduced to industry since that meeting and brief summary of their application and progress follows.

These electrodes are designed especially for downhand, high-speed, deep-groove welding (see Fig. 4). They may be used with either ac or dc but to best advantage with ac. They may also be used for fillets. Electrodes in this class are, for the large part, mild steel.

Properly qualified electrodes have been approved by the American Bureau of Shipping, the United States Coast Guard, Lloyd's Register of Shipping, and have been used for welding done under the inspection of Hartford Steam Boiler Inspection Insurance Company. Test specimens of typical electrodes are shown in Figs. 5, 6 and 7.

Physical properties correspond in general to conventional E-6020 electrodes except for low-temperature impact properties. Typical values:

As-welded:	
Tensile, psi	62,000–67,000
Yield, psi	52,000–57,000
Elongation in 2 in., %	25–32
Impact resistance:	
Charpy-keyhole	
37 ft-lb at room temperature	
22 ft-lb at −100° F	
Transition temperature: below −100° F	

(Electrodes are also available in higher tensile strength steels for welding 70,000 psi steels.)

* "Iron-Powder Electrodes and Their Application," Jerry Hinkel. See The Welding Journal, Sept. 1954, p. 847.

Fig. 5 Typical samples welded per ASME test requirements

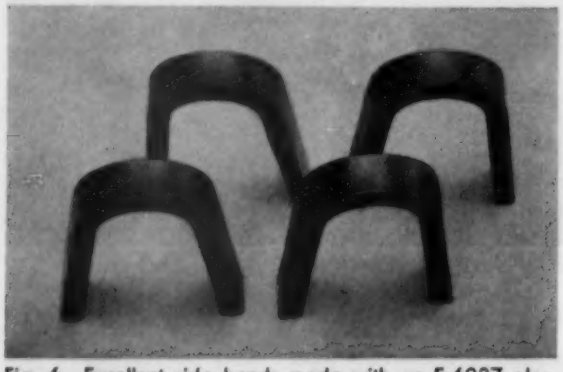


Fig. 6 Excellent side bends made with an E-6027 electrode. These tests were made in the as-welded condition

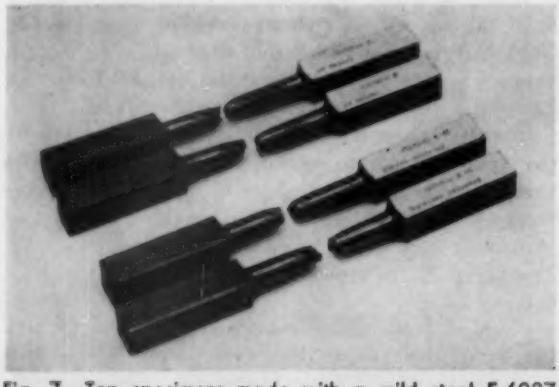


Fig. 7 Top specimens made with a mild steel E-6027 electrode in the as-welded condition. Lower specimens made with high-tensile E-6027 electrode stress relieved. Both have a minimum of 25% elongation

The electrodes produce savings through high deposition rates which permit welding speeds up to 50% faster.

As with other iron-powder electrodes, they are contact electrodes and best results are obtained using this technique, although an arc may be held and offers advantages under some conditions.

The bead appearance is excellent with very good wash-in properties. With correct procedure, the cover pass appearance is comparable to welds made with automatic submerged arc (see Fig. 8). For cover passes, the weldment should be flat, speed of travel should be low enough to insure complete slag coverage, stringer beads rather than wide weaves should be used (see Fig. 9) and the electrode should be kept nearly perpendicular to the work.

Although the electrodes are designed specifically for deep-groove welding, fillet welds made with them are excellent in appearance, equal to or better than conventional E-6020 electrodes. Speed is somewhat less than that obtained with E-6024 electrodes which were designed for fillet welding. Spatter loss is extremely low which, consequently, means less cleaning time and much better appearance.

The electrodes are capable of meeting any of the usual X-ray requirements. The surface porosity condition which is common to all conventional E-6020 and E-7020 electrodes, especially on fillets, is virtually nonexistent The electrodes are less crack sensitive on medium carbon steels than conventional electrodes (see Fig. 10).

Reaction to Iron-Powder Electrodes

During the one-year period in which iron powder electrodes have been available, almost every potential user has been exposed to one or more of them. The reactions have varied but in all cases the products have been: (1) accepted, (2) rejected or (3) are still being investigated.

"Accepted"

In a great many cases, a brief demonstration or a short field test trial has been sufficient to establish the superiority of iron-powder electrodes and to justify almost immediate replacement of the conventional electrode. But it has not been so simple in all cases. Especially with large volume users, it can be a slow and tedious process to satisfy all interested parties as to the merits of the product.

The larger the company, the slower the process has generally been. In many cases it has involved shop level demonstration testing, laboratory testing, field test trials of welded assemblies, close scrutiny by cost departments, time study and methods departments. The fact that so many of these electrodes have come through all this testing with flying colors is ample indication that they do represent a lasting and worthwhile development.

"Rejected"

It would be a pleasure to report that no one has found it necessary to reject iron-powder electrodes, but that is not true. The designers of iron-powder electrodes would be the first to admit that the present designs do not represent the perfect answers to all of various types of applications in existence today. Many of these applications can still be handled to the best advantage with conventional electrodes.

Because of the tremendous interest being shown in iron-powder electrodes, they are frequently being tried and tested on applications for which they are not well

suited and for which they are not recommended. Many of the rejections fall into this category.

Rejections have sometimes occurred somewhere along the long road of tests involved in satisfying all interested parties in a large-scale operation. When such tests involve many different departments, it is not surprising that it should fail to measure up to some one department's or some one individual's standards of acceptability.

"Still Being Investigated"

The acceptance and sales of iron-powder electrodes have been exceptionally gratifying in the short time they have been available, and yet it is quite evident that many of the large potential users are not yet using them because they are still in the process of investigating them. To the eager sales-minded individuals, these delays have been very frustrating, but it speaks well for the integrity and sense of responsibility on the part of the electrode user.

Many larger customers are spending considerable time and money conducting tests of their own to establish with certainty the suitability of these electrodes. Unfortunately, these tests are usually very slow in producing conclusive information.

It is the hope of all concerned that such testing programs will eventually establish the facts and indicate approval or rejection on the true merits of the products and will be based on realistic test conditions which will apply to the weldments normally involved.

It is not uncommon to find a large-scale investigation conducted almost entirely on a laboratory level with little or no regard to the conditions, limitations and requirements which are peculiar to the type of work actually being done. The natural reaction of such an investigation is to give enthusiastic approval on the basis of impressive results of physical properties, X-rays, impact resistance, etc., only to find that the electrode may have usability characteristics which render it practically useless for the job for which it is intended.

For example, such testing would inevitably show a strong preference for E-6027 electrodes over E-6024 type. But if the actual shop conditions involve such things as welding poor fit-up short intermittent welds, welding steels of relatively poor weldability, making multiple or even single-pass fillets, then the E-6024 type would be far better suited.

Summary

In the brief period in which iron-powder electrodes have been available, they have proved that they offer some very real advantages over conventional electrodes. But because their operating characteristics are noticeably different, there have been problems in effecting a direct replacement of conventional products. Some of these problems have been related to usability characteristics; others have been relative to code requirements or electrode specification requirements. In most cases these problems have been successfully worked out.

At the present time, those electrodes which will eventually be known as E-6024 are enjoying the greatest popularity.

The continued interest in these products indicates that they are making a significant contribution to industry's cost reduction efforts and that they represent a major development in the welding industry.

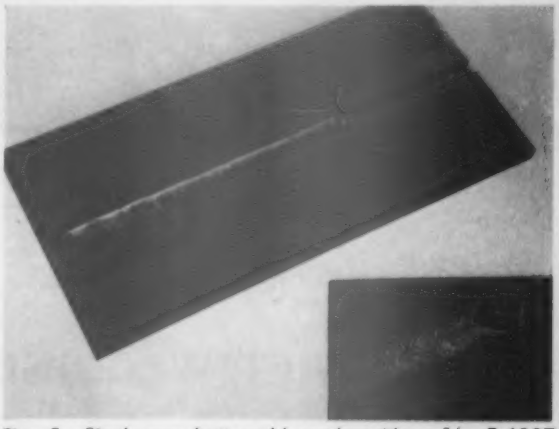


Fig. 8 Single-vee butt weld made with a $^{3}/_{16}$ E-6027 electrode has excellent wash-in and cover pass appearance

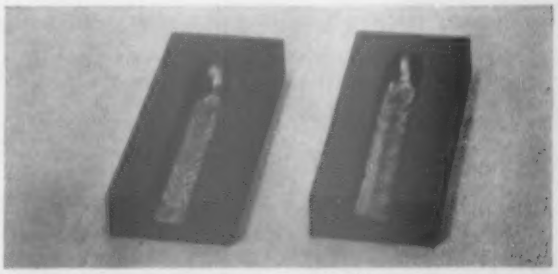


Fig. 9 Full weave used on the left, split weave used on the right. The split weave is recommended wherever practical for best results

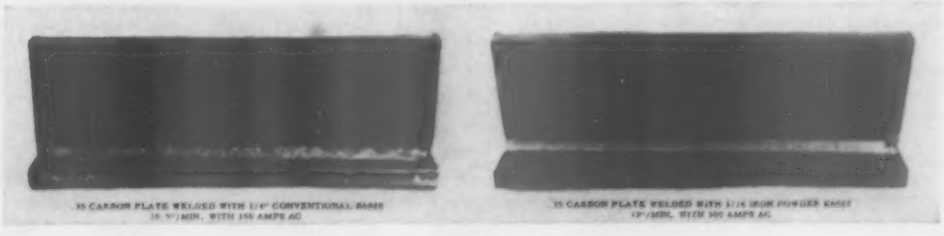


Fig. 10 The E-6027 electrodes are less crack sensitive on medium carbon steels

Fig. 1 "Tie-down" (fatigue) test of the Air Force YH-16 "*Transporter.*" This is the world's largest transport helicopter.

FATIGUE ASPECTS IN AIRCRAFT WELDING DESIGN

The designer of welded aircraft parts and assemblies must be particularly fatigue-conscious. He should avoid the more harmful and complex stresses in a weld and thus minimize the danger of fatigue failure

BY J. KOZIARSKI

ABSTRACT. Unlike his predecessors, the designer of modern aircraft must be, and is, fatigue conscious. Cyclic stresses produced by service loads, vibration, gusts, etc., must be given particular attention in aircraft designing. Welded joints are inherently notch-producing. The effect of residual stresses on fatigue properties of weld seem to be considerable, but is very difficult to be numerically evaluated. The most common error in design of welded aircraft structures is failure to allow wide enough edges. A designer of aircraft welded parts or components should avoid such conditions as excessively high structural rigidity, design-in or metallurgical notches, nonhomogeneity of material, resonant vibration, etc. He should give preference to joints working in tension to those working in shear. The old fashioned "reinforcement" does reinforce a weld statically but weakens it dynamically. Particular care should be taken when designing with notch-sensitive alloys. Fatigue data for brazed joints is almost nonexistent. There are potential possibilities of increasing the fatigue life of a weld. *S–N* curves are very useful in development design work.

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Introduction

Wood, fabric, steel wire and steel sheet were almost exclusively used in the airframe and a few simple steel, aluminum and copper alloys—in the engine of the aircraft flown in the "heroic era" of aviation. The ignition system was the only electrical device installed on the early aeroplane, which was flown by the pilot by using visual navigation, sometimes flying the "iron beam" (a railroad) or along the river as the only navigational aid.

Vibrations and gusts were considered as a nuisance rather than a danger. The old time designer was concerned almost exclusively with the static strength of the aircraft he designed. Loads acting on the main aircraft components were calculated from the wind tunnel data and for different "flight conditions." These loads, multiplied by arbitrary safety factors, produced design loads which served as the basis for stress analysis. Furthermore, the aircraft of those days was considered as a rigid body which also simplified the task of the designer.

Higher and higher speed, higher ceiling, higher load/weight ratio, better durability, etc., are required from modern aircraft, loaded with electronic "brains" and electric "nervous system." These requirements pose new, previously unknown problems, such as service in extreme temperatures, aerodynamic friction heat, thermal shock, etc., and above all, fatigue. We may safely state that nothing in a modern aircraft works statistically. In fact, this was also true of the old "flying crates," but it was not so much appreciated as today. Fatigue, "discovered" about 130 years ago, only recently has been given due attention.

Fatigue failures are caused by cyclic loading which, in turn, in a fixed wing aircraft depend primarily on the excitations produced by the engines, aerodynamic loads, vibrations, gusts, etc. Gusts to which more and more attention is paid[1-5] are considered as being the primary cause for wing fatigue of long range transport (or bomber) aircraft. Chilver[6] even states: "Fatigue damage in the wing structure is caused largely by. . .low-velocity gusts which occur relatively frequently in flight."

Dynamic loading in a helicopter is perhaps even more complex. Cyclic forces developed by larger rotating blades, long transmission shafts, high-ratio reduction gears,[7] etc., make the rotary wing aircraft a very complex vibrating structure.

The aircraft designer nowadays turns more and more toward the 'dynamic" rather than toward the "static" stress analysis. There exist, however, enormous difficulties because of the lack of data. *S–N* curves as given in different publications in the majority of cases refer to standard polished specimens. Consequently, they are of little use for direct application to an aircraft stress analysis. Rather whole families of *S–N* curves for different surface, structural and temper conditions are needed. These, unfortunately, are not available in the majority of cases.

Furthermore, the fatigue properties of a welded (or brazed) joint are even less known because of the additional parameters involved. These parameters make fatigue testing of a weld still more difficult and complex.

In the "good old days," the designer had only one check to make to see whether his structure was sound, namely, static test. Aircraft components, or even the whole aircraft, were turned upside-down and loaded with sand bags to destruction.

Today, whereas the engine designer is rather interested in the endurance limit of an alloy, the aircraft engineer looks more often toward the fatigue life of an entire assembly or component or even of a complete aircraft (Fig. 1). Unfortunately, as Teed says:[10] "No one can accurately forcast the endurance of a component containing stress concentrations." The fatigue life of an entire aircraft may depend on its weakest link. Like constant overstraining of a foot tendon may prevent a man from walking although the rest of his body is physically fit, a broken screw may prevent an aircraft from flying. However, the man will stay on the ground while the aircraft may fall to the ground as it cannot stay motionless in the air.

It would, of course, be extremely helpful if either the endurance limit of a metal or the fatigue life of a component were possible to predict without their destruction. This, so far, is impossible in spite of some very interesting works in this field.[11, 12]

The successful behavior of a machine in service depends on four factors:

1. Design.
2. Materials.
3. Manufacturing.
4. Service.

According to some authorities,[13] 80% of machine part failures are due to fatigue and it is also generally accepted that the majority of fatigue failures are due to design and manufacturing. Almen[14] and Cazaud[9] state that this amounts to 90%. This figure has been confirmed by Carlson and Schnebly[15] who gave the following percentages of fatigue failures for one particular type of helicopter as attributed to: field errors, 10%; manufacturing errors, 30%; and design errors, 60%.

Fatigue problems in aircraft design should be considered mainly from four points of view: residual stresses, stress concentration, resonance and material properties. These will be the major topics in our considerations.

Residual Stresses

Residual stresses have for some time been recognized as having considerable effect on both the static and dynamic properties of materials, joints and assemblies. It has been found that residual stresses, depending on their character, either decrease or increase fatigue properties as they add algebraically to stresses produced by external loads.

There exists a considerable number of publications concerned with residual stresses and their effect on the strength of metals and joints, including welds. Below are listed some of the recent works dealing with this problem.[8-10, 13, 16-24]

Effect on Fatigue of Welds

Residual stresses cannot be neglected by any designer of aircraft components. Unfortunately, the effect of residual stresses on the fatigue strength of a weld is very difficult to be separated from other effects such as of mechanical and metallurgical notches, surface condition, etc.

There are various sources of residual stresses in a

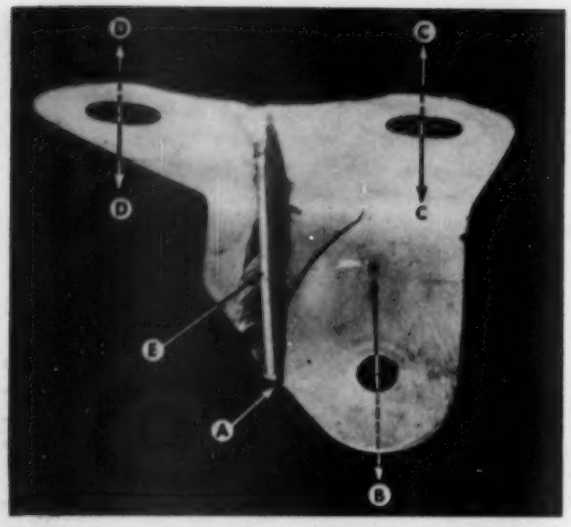


Fig. 2 Fatigue failure due to excessive structural rigidity and design asymmetry

weld such as: temperature gradient, shrinkage, restraint, phase transformation, solid or gaseous precipitations, decarburization, etc.*

Consequently, authors and research workers, among them Benson, Spraragen and Bijlaard,[13] Templin and Hartman,[18] Almen,[23] Cazaud[9] and Soete and Van-Crombrugge,[35] are approaching the effect of residual stresses on fatigue of welds with great care, although they recognize their importance.

There exists a difference of opinion as to the character of the stress which produces a fatigue crack. Almen[23] states that only *tension stresses* produce fatigue fracture when Wållgren[36] indicates that compressive stresses may also cause a fatigue failure. The compressive fatigue, however, seems to be accompanied with local compressive deformation. In the case of aircraft welded joints, tensile stresses seem to have more effect on fatigue than compressive stresses.

Residual stresses may actually produce cracks in the weld before the part even starts to be stressed in fatigue. They may occur immediately after welding and be easily picked up by inspection or they may open after some time in storage, after they have been accepted by inspection. These defects may have a character of macro or microcracks. The latter ones usually avoid any detection by inspection. They may be located in some grains and along grain crystallographic planes. Depending on the elastic properties of grains or their particular planes,[9, 10, 27] microcracks may produce either local stress relieving or they may act as conventional notches in fatigue. Furthermore, residual stresses not relieved by cracking may actually add to working stresses in the piece and produce fracture during service.

* The decarburization may be the cause of outer fiber tension stresses because the expansion accompanying the austenite-martensite transformation under the decarburized surface results in the accompanying compressive balancing of stresses in the outer decarburized fiber.

Finally, residual stresses may be relieved by local plastic flow during service.

Stress Concentration

Structural Rigidity

The opinion concerning correlation between ultimate strength, yield point, elongation and impact changes with time. It is generally accepted today that there is only some limited relationship between the ultimate tensile strength of some alloys and their condition and the endurance limit. Test results seem to indicate that there is no such correlation in the case of an unwelded alloy and a welded joint. However, MacGregor[22] seems to indicate that there exists some relationship between fatigue and impact strength and transition temperature of a metal.

Sometimes there is an advantage in structures, to have some structural flexibility and material ductility.[19, 26] The former permits better stress distribution and the latter stress relieving by local deformation (local plastic flow).

Reference 38 (Figs. 4, 6, 7 and 8) gives some explanation of this problem. An aircraft designer can relieve or decrease a stress concentration by skillful positioning of welds, by the geometry of the joint, by the choice of sections and by the choice of suitable material and its condition. Figure 2 is a good example of the lack of flexibility in an asymmetrically designed part. A bracket, attaching engine cowling to the engine, was persistently failing in fatigue. The fatigue crack always started at *A*.

Analyzing this problem, the cyclic load has been applied at *B-B* and reactions at *C-C* and *D-D*. Of course, there was a powerful stress concentration at *A* due to the unbalanced shape of the bracket, and one-sided rigidity produced by the gusset.

There also were two other design errors. First, the gusset *E* came to the edge *A* of the bracket; and second, the weld was positioned on the wrong side of the gusset, both errors producing a notch at *A*. Besides, manufacturing also made an error by not carrying the weld end around the end of the gusset to reduce this notch.

As a remedy, the elimination of the gusset, the slight increase of the sheet thickness, and a better contour produced satisfactory results.

Shear vs. Tension

Some government specifications require that whenever possible welded joints be designed so that the weld be loaded in shear.[39] This requirement which recently has been dropped from some specifications has produced considerable confusion in design and stress analysis.

The opinion that a weld metal should be loaded in shear rather than in tension is an atavistic prejudice dating to the "heroic times" of aviation when in some circles welding was considered unreliable and uncontrollable.

There exist considerable data concerning the strength properties of a weld working in shear and in tension.[9, 12, 33, 35, 40–43] These data prove that the butt

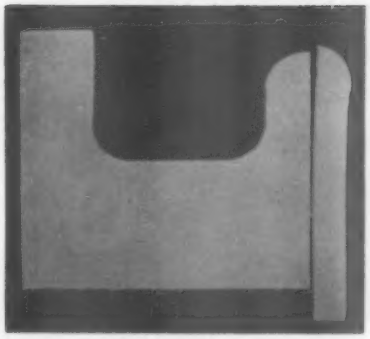


Fig. 3 Fatigue failure of a weld between heavy 5052-0 plate and thin 5052-0 sheet produced by combined shear-bending loads

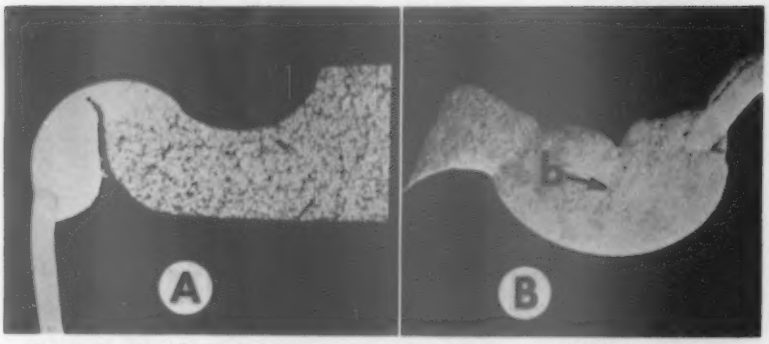


Fig. 4 Lack of fusion in inert-gas-welded aluminum alloy (Keller's Etch, X 5)

(A) (Left) 5052-0 sheet; (right) 43 aluminum cast plate. Very low static load. No fatigue crack. (B) (Left) 43 aluminum alloy cast plate; (right) 5052-0 sheet. Fatigue fracture (b) starts at the bottom of the lack of penetration.

weld, i.e., a weld working on tension or compression, possesses the best static and fatigue properties, transverse fillet weld being the second and longitudinal fillet the third.

Hartman, Holt and Zamboky[41] give the following results with 6061-T6 aluminum alloy, $^3/_8$-in. plate, metal-arc welded on both sides with the use of 4043 aluminum alloy filler metal (Table 1).

The limited space does not permit a detailed explanation as to why tension or compression (as in butt weld) is superior to shear (as in fillet weld) in fatigue. However, some consideration may be found in the WELDING HANDBOOK[42] and in one of our earlier papers.[35] The desaxiality of the joined sections, high weld-end stresses, notch effect, high shrinkage stresses and bad welding conditions of the weld end are the most responsible factors in the inferiority of a weld working in shear to one working in tension or compression.

Figure 3 shows a section of a failed corner weld made by inert gas welding between a 0.50-in. 5052-O aluminum alloy plate and 0.064-in. 5052-O sheet of an experimental part.

Although the main load *a* (Fig. 6*A*) should produce pure shear stresses in the weld, there also were some side cyclic bending loads *b-b* which produced high stress concentration in the gap that resulted from a lack of fusion between the plate and the sheet. (This lack of fusion is very common in flange welds and especially in those made with the inert gas.)

Figure 4 shows similar joints made by inert-gas shielded-arc welding and taken from an experimental oil tank. Both photomacrographs show the lack of fusion. However, Fig 4*A* represents a very lightly and mainly statically loaded joint between 43 aluminum alloy cast plate and 5052-O aluminum alloy sheet. This joint did not fail in spite of a very small area fused. Figure 4*B* presents a weld which was subjected to cyclic side loads. It shows a fatigue fracture although the penetration and fusion are much better than in Fig. 4*A*. In Fig. 5 an enlarged detail from Fig. 4*B* is represented. This crack partly intergranular and partly transgranular may look a little peculiar as it does not show typical "lightning"-like path. It, however, seems to follow the plane of weakness produced by the junction among columnar grains in the cast weld metal.

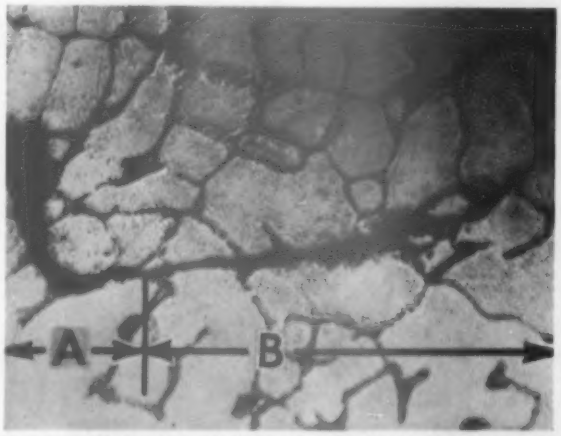


Fig. 5 Enlarged crack *b* from Fig. 4*B* (Keller's etch, X500)

(A) The end of the lack of fusion. (B) Partly transgranular, partly intergranular fatigue fracture.

In Fig. 6, incorrect and correct joint design in the discussed case is given.

Reinforcement

In the "old times" the "reinforcement" of the weld was a must. No machining of the weld was permitted. This was because a weld with reinforcement showed

Table 1—Static and Fatigue Strength of Butt and Lap Joints in $^3/_8$-In. 6061-T6 Aluminum Alloy Plate Arc Welded on Both Sides with 4043 Filler Metal[41]

	Ultimate tensile strength, psi	*Endurance limit, 10^7 cycles, psi*
Butt welded	26,700	6300
Lap joint, transverse fillet	9,770	1500
Lap joint, longitudinal fillet	8,750	700

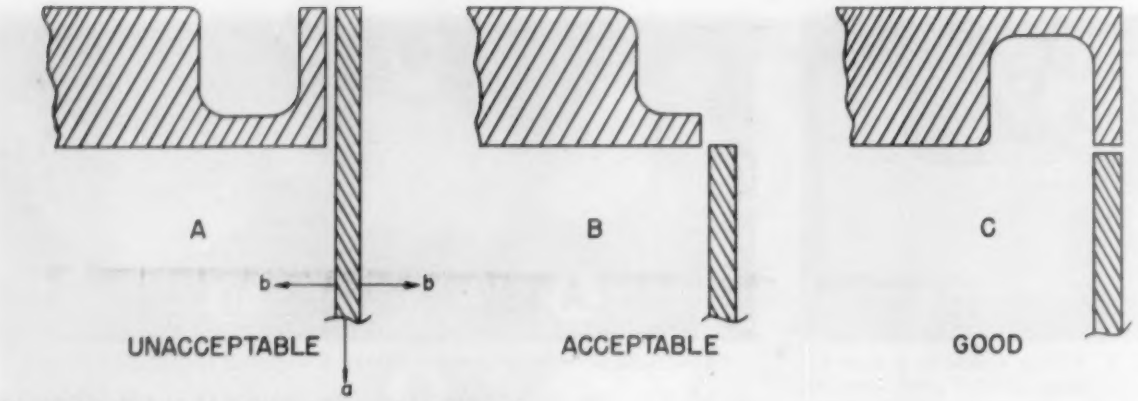


Fig. 6 Weld between a heavy plate and a light sheet

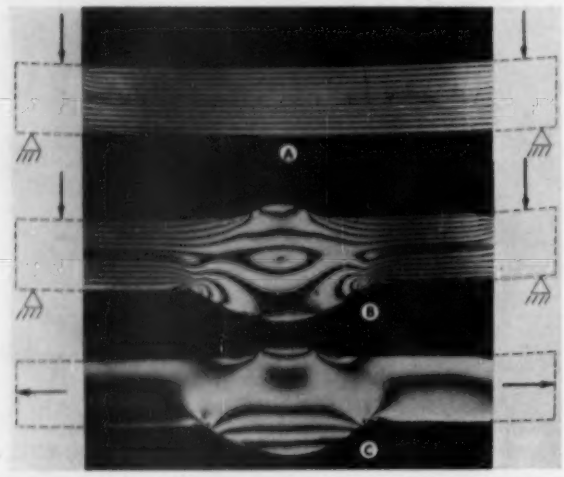


Fig. 7 Photoelastic stress pattern in a simulated weld of aircraft proportion

(A) Unwelded plate; uniform bending load. (B) Welded plate; uniform bending load; tensile stresses (bottom) identical to (A) in the base material. (C) Welded plate under uniform tension.

higher static strength than one with the surplus metal machined off.

There exists enough data today to show that the requirement is dynamically wrong.[9, 10, 33, 35, 40–44] On the contrary, there is a marked improvement in fatigue strength of a dressed weld.

Templin and Holt[40] give the fatigue strength of 3003 (3S) aluminum plate and sheet, on which the weld has been dressed, to be 2.2 to 2.7 times higher than that of undressed one.

Hartman, Holt and Zamboky[41] found the following values for $^3/_8$-in. 6061-T6 aluminum alloy plate metal-arc welded with 4043 aluminum alloy filler metal (Table 2).

Erker[44] states that the endurance limit, for mild steel plate arc welded on both sides and tested in pulsating tension fatigue, is 70 and 90% of an unwelded plate for specimens with undressed and dressed welds, respectively.

Figure 7 shows why the fatigue strength of a welded joint with dressed weld is superior to one with undressed weld. It represents photoelastic stress patterns in plates simulating welds of proportions as met in light section aircraft joints. Figure 7*A* represents an unwelded plate bent by concentrated loads (constant bending moment). Stresses are uniform through the entire section. Figure 7*B* shows same plate as 7*A* but with a weld. The true stress concentration factor at the toe of the weld and for this particular material is 1.33. Figure 7*C* gives same bar as 7*B* under tension. As may be seen, the neutral plane has been slightly deflected due to some bending in the joint.

Of course, the stress distribution in plates of such proportion would be only qualitative because identical notches in other materials may produce different true stress concentration factors. It is obvious that the heavier the reinforcement, the more the notch has effect on the strength of a weld.

It must, however, be pointed out that only reinforcements of a sound butt weld can be safely machined off in order to improve the fatigue resistance of the joint.[45] The machining of welds of uncertain quality, or of welds other than butt welds, should be prohibited unless it is done for special purposes and with special precautions. This will be explained partly in the next paragraph.

Edge Width

One of the most common welding design errors is a too narrow edge which does not permit accommodation

Table 2—Static and Fatigue Properties of Butt Joint in $^3/_8$-In. 6061-T6 Aluminum Alloy Plate Welded on Both Sides with 4043 Aluminum Alloy Filler Metal With and Without Reinforcement[41]

	Static, psi	*Fatigue, psi*
With reinforcement	26,700	6300
Reinforcement machined off	23,400	7500

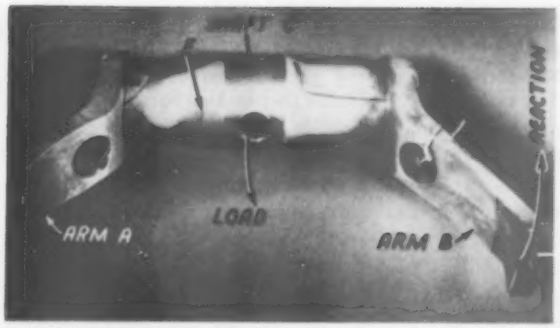


Fig. 8 Fatigue failure in shear of a clutch yoke due to too small edge width and due to machining the weld

Fig. 9 Machined weld between shaft C and arm B from Fig. 8

of a sound weld.[33] The results of such a design are sometimes disastrous. This is because there is a tendency by the welder either to burn the too narrow edge or to produce lack of fusion. Also there exists a danger of undercutting the weld during machining.

An experimental friction clutch yoke made from SAE 4130 steel failed in shear fatigue after only about 500 engagements (Fig. 8). Figure 9 shows a machined face of the weld between the arm *B* and the shaft *C*. The fracture, produced by the two-dimensional shear stresses, started at *D* (Fig. 9), progressed through the weld around the shaft and at *E* proceeded into the shaft *C*. *F* (Fig. 8) shows the end of one of the cracks.

The main cause of failures was too narrow an edge called on the drawing. It was only 0.087 in. while it should be 0.35 (Fig. 10*A*) in order to accommodate the weld. In such circumstances, the weld could not be of good quality.

Another design error consisted of calling for machining of the welds (Fig. 9). The results of this may be seen in Fig. 11. Here, *A* shows a section longitudinal to the shaft and through the arm which indicates that the fusion was poor, and *B* brings another similar section with a porosity.

Also the weld was designed on the wrong side of the arm. It should be positioned at *F* (Fig. 10*A*).

A good solution would be to design the joint for brazing as shown in Fig. 10*B*. In fact, this would be an ideal application for copper or brass brazing. Silver filler metal could not be used because the assembly had to be heat treated after welding.

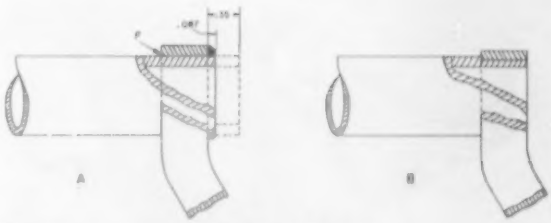


Fig. 10 Design details for the failed yoke
(A) Incorrect design. (B) Correct design; brazed joint.

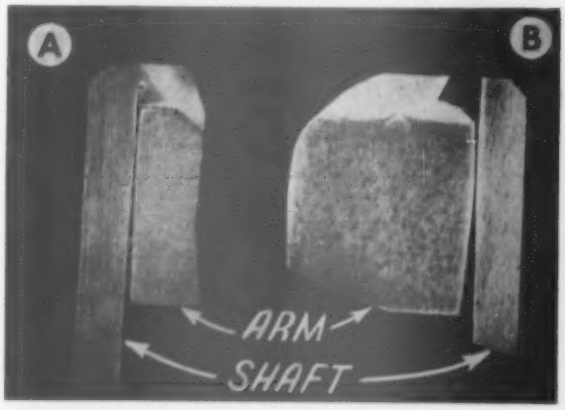


Fig. 11 Section through welds from Figs. 8 and 9
(A) Lack of fusion. (B) Blow hole exposed by machining.

Design-In Notches

A weld inherently produces mechanical and metallurgical notches.[35] Mechanical notches may be due to either the geometry of the weld joint or to such defects as lack of fusion, lack of penetration, slag inclusions, blowholes and undercutting. They all produce stress concentrations. Metallurgical notch is due mostly to the heat effect in the heat-affected zone.[36]

These notches, being hereditary, cannot be completely avoided but their effect may be minimized by a suitable design, i.e., by an economical arrangement and geometry of welds.[28]

For example, let us discuss an exhaust manifold made from AISI 321 corrosion and heat-resistant steel which failed in fatigue after about 200 hr of operation (Fig. 12). The joint was a lap straight joint between 0.093-in. collar and 0.72-in. tube and was subjected to vibratory bending loads. The fracture started in the heat-affected zone at the toe of the weld (*A*), progressed along the weld and ended in a shear failure (*B*).

There were three causes of the failure. First: Stress raisers contained in one working section all around the tube circumference.[38] Second: The joint was a lap joint which produced additional bending loads in the weld due to the offset of the neutral planes.[38] Third: A sudden change of section from 0.093 to 0.072 in. which also produced a notch.

There are four solutions to this problem as shown in Fig. 13 in the order of increasing quality. This is self-evident and it does not require any further explanation. It should also be pointed out that the ends (*E*, *F*) of the scarf (Fig. 14) should be positioned on the neutral plane of bending in order to avoid high stress concentrations.

Such lap joint as described in this section may also produce fretting which, in turn, may be the cause of fatigue failure.

Lap joint in parts working in hot combustion products is also disadvantageous because of combustion residues trapped in between the walls. Those combined with the condensation of the moisture may produce concentration cell corrosion when the engine has been stopped and the exhaust manifold has been cooled down. This, in turn, may lead to stress or fatigue corrosion.

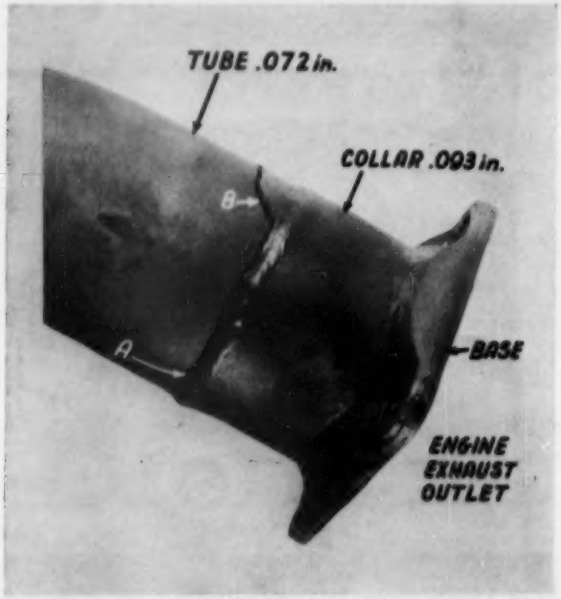


Fig. 12 Fatigue failure of an exhaust manifold. Lap joint between AISI 321 steel tubes of different thickness. Design-in notch
(A) The start of the fatigue crack. (B) Shear crack.

Resonance

Resonance is considered as one of the biggest enemies of the aircraft. This is because even an insignificant cyclic load may cause a failure if in resonance with natural frequency of a part, assembly or component. Resonant vibration is especially dangerous because it is difficult to foresee as the exciting load may elastically be transmitted far away from the part concerned.

A good example of this follows. Ends of an exhaust collectors made from 0.050-in. thick AISI 321 corrosion and heat-resisting steel persistently failed in fatigue along the toe of the flange weld (Fig. 15).

Here, there were two design errors: specification of flange welding and leaving the weld with the reinforcement unground.

It is very difficult to produce a flange weld without residual notches which result from insufficient bending radius of the flange. Stress concentration produced by such notches add to stress concentration due to reinforcement (see previous section on Stress Concentration: Reinforcement).

Exhaust gases produce pulsating impulses which, when in resonance with the natural frequency of the tube (Fig. 16) may produce very high deflections in the

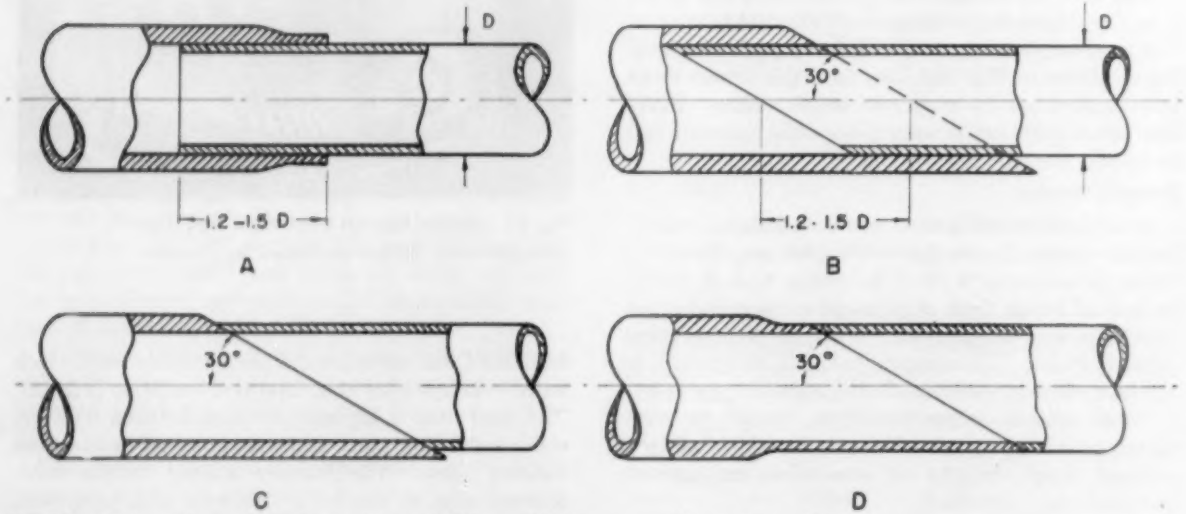
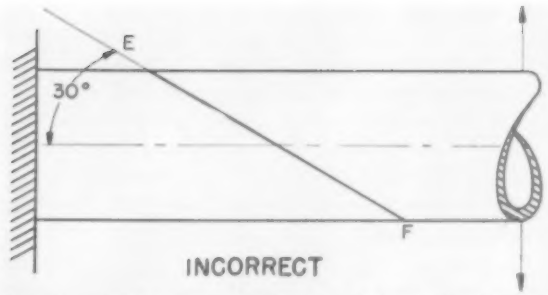


Fig. 13 Designs of a weld between tubes of different thicknesses working under cyclic loads



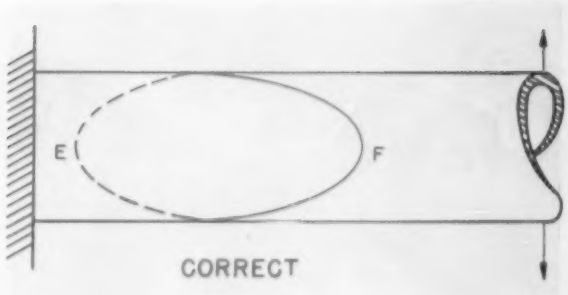


Fig. 14 Position of a scarf joint in relation to bending loads

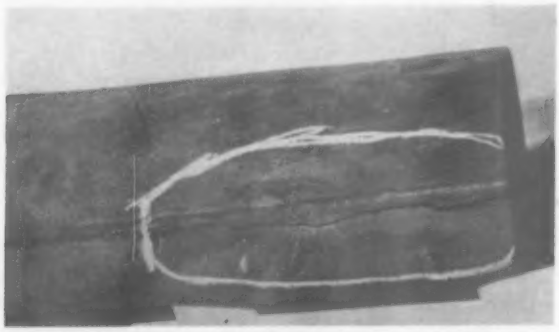


Fig. 15 Fatigue crack in the toe of the weld with reinforcement probably caused by resonant vibration. AISI 321 steel. Inert gas welding

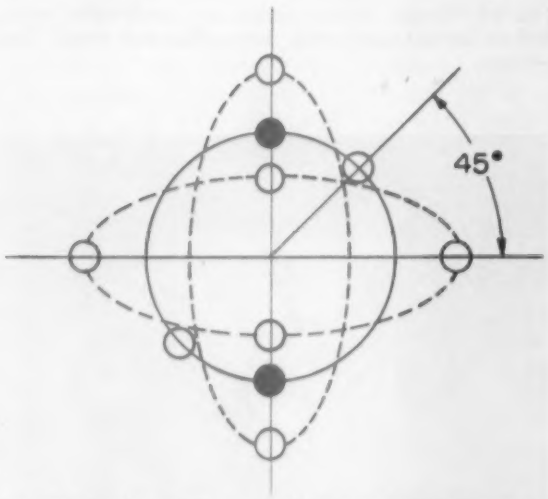


Fig. 16 Position of the weld in relation to deflection of the tube caused by vibrations in the normal plane

normal plane and, finally, a fatigue failure may occur. This probably was the case of the failure in the discussed example, although neither the natural frequency of the exhaust end was checked nor its resonance positively proved.

Concluding, in the case of a vibrating-in-normal-plane tube, the following should be observed:

(*a*) Butt weld should be used.
(*b*) Weld should be as flat as possible or it should be ground flush at least at the end of the tube.
(*c*) The face of the end of the tube should be deburred smooth.
(*d*) The welds should be positioned at 45 deg to the plane of the maximum deflections (Fig. 16) if such have positively been established by a test.

It must be noted that, in very thin sections, the ratio of the thickness of the reinforcement to the tube thickness is relatively high (Fig. 17*A*). Of course, the weld metal has higher mass than a similar section of the tube. Consequently, its vibration period and frequency are different than those of the tube. This will create additional loads at the change of section *a* (Fig. 17*A*).

In case of cantilever bending of such a tube, the welds should be positioned at the neutral plan (Fig. 17*B*).

It is almost impossible to foresee the type of vibration to which the part will be subjected. Consequently, only a test would indicate the type, frequency, planes and amplitudes of vibration.

Fig. 17 (*A*) Vibrating tube with a reinforced unground weld. (*B*) Position of a longitudinal weld in relation to bending load

Material Properties

Ductility

An aircraft designer must well understand and take into consideration properties of materials from which his aircraft is to be made.

One of the important properties of an alloy is its ductility. This is especially true in fatigue. Unfortunately, the ductility has never been properly defined.[50] Usually, the elongation and the reduction of area are taken as an indication of "ductility" of an alloy.

It is not the author's purpose to go too deep into this matter. However, it may be stated that not only a high elongation and a high reduction of area are desir-

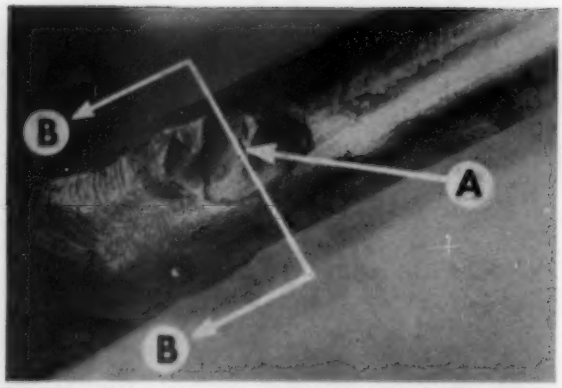


Fig. 18 Fatigue cracks caused by metallurgical notch. SAE 4130 steel base metal. Low-carbon filler metal. Gas welded

Fig. 19 Section *B-B* through the crack from Fig. 18 (2% Nital, X 30). As shown, crack propagates only in the light ferritic area

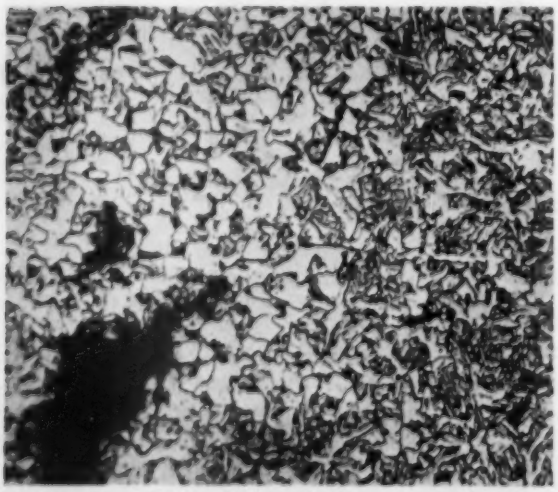


Fig. 20 Magnified end of the fatigue crack from Fig. 19 (2% Nital, X500). Note that crack was arrested in the martensitic area

able in the material, from which an aircraft component is made, but also the elongation and reduction of area should not be confined to a too narrow area. Otherwise speaking, a sudden, narrow necking is undesirable especially from the fatigue point of view.

Stress concentration may be reduced in a ductile material by a local plastic flow and, thus, it may decrease the danger of a fatigue failure.

Metallurgical Notch

Someone said: "A chain is as strong as its weakest link." One may also say with the use of a liberal travestation: "A welded assembly is as strong as its weakest point." Suppose an assembly consisting of an alloy steel, heat treated after welding to 180,000 psi, is welded with a very low-carbon steel filler metal having a strength of about 35,000 psi. The strength of the weld metal will probably be about 50,000–60,000 psi due to the pickup of carbon and of alloying constituents from the base metal. Consequently the *strength of the joint* may be not 180,000 psi, as expected, but only 50,000–60,000 psi, i.e., *the strength of the weld metal.*

To illustrate this, fatigue cracks *A*, were spotted in gas-welded brackets (Fig. 18), components of which were made from SAE 4130 steel. The brackets were heat treated after welding to 125,000–145,000 psi. The parts had about 200 hr of operation or about 3,000,000 cycles at the moment of detection of the crack.

Some of the cracked parts were given an accelerated fatigue test. There was no complete fracture even after 30,000,000 cycles and even when the steady and cyclic loads were increased to 200% of those calculated.

An analysis shows that fatigue cracks started in the weld metal at the weld end where welding conditions are unfavorable.[23] The sudden change of section, usual lack of fusion, etc., produced a powerful notch and stress concentration. Section *B-B* (Fig. 18) through the crack is shown in Fig. 19 and its magnification in Fig. 20. The crack started and continued in a light structure, composed mainly of ferrite (probably alloyed). It stopped at the dark area (Figs. 19 and 20). This area was primarily composed of tempered martensite.

The hardness of the light structure was about 166 DPH and it progressively increased to about 320 DPH in the dark area. This would roughly correspond to 76,000 and 150,000 psi, respectively. It was, therefore, not surprising that cracks started in the light area. Later it was found that the nonheat-treatable filler metal had been used for welding those brackets.

The lack of complete failure during the accelerated fatigue test may tentatively be explained by the presence of compressive stresses in the martensitic area. The tensile stresses in the ferritic area may have been relieved by cracks which were stopped in higher strength martensitic structure which still may have contained some residual compressive stresses. It is also possible that the stress analysis was wrong and that the part was overdesigned.

A similar crack in the weld which would not produce

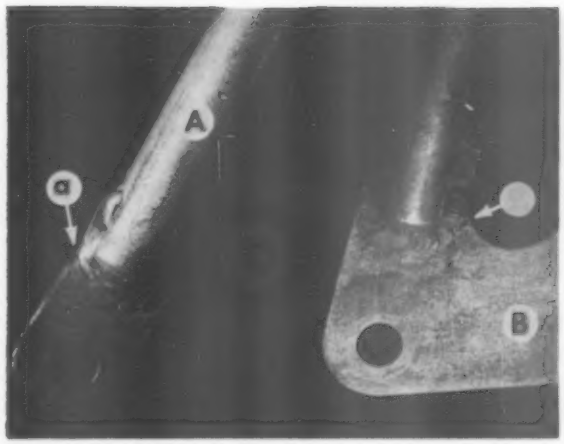


Fig. 21 Fatigue crack caused by structural heterogeneity. SAE 4130 steel base metal. Low-carbon filler metal
(A) Electric arc welded. *(B)* Gas welded.

Fig. 22 Photomacrograph of the crack from Fig. 21*B* (2% Nital, X30). As indicated, crack propagates in the diluted area on the flat surface just underneath the toe of the weld

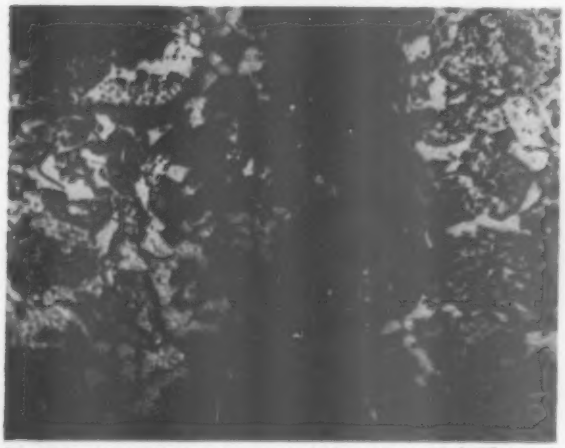


Fig. 23 Magnified fatigue crack from Fig. 22 (2% Nital, X1000). Crack seems to propagate through light grains

failure has been given by Almen.[23] In his case, however, those parts which were stress relieved failed and those nonstress relieved did not.

It may be concluded that a heat-treatable filler metal either should be specified on the drawing when designing parts which are to be heat treated after welding or the manufacturing standard practice should be to use heat-treatable filler metal when welding such parts.

Alloy Homogeneity

Teed[8, 10, 17] very emphatically stresses that fatigue starts in weak grains. Dolan and Yen[51] indicate a high decrease of the endurance limit as the result of the lack of structural homogeneity of slack quenched steel when tested in notch fatigue. Jackson and Pochapsky[52] and Gadd[28] discuss the effect of the decarburized surface of steels having different core hardness. Finally, Voldrich and Armstrong[53] give interesting results of fatigue tests on SAE 4130 steel in as-rolled (decarburized) and ground conditions. Although the authors do not want to draw final conclusions, they, however, indicate a possible lower fatigue strength of welds made from the former than from the latter material.

As pointed out above, the weld is inherently notch bearing. Consequently, any metal heterogeneity will produce the decrease of the fatigue of the weld although its static strength may not be affected.

A number of identical brackets, as described in the preceding section showed fatigue cracks which started where the lug was thinned by the heat (*a*, Fig. 21*A*) and either followed the heat-affected zone (*b*, Fig. 21*B*) or went through the weld (Fig. 21*A*). Cracks appeared on the first bead side after only 4 hr of operation or after about 60,000 cycles. The bracket in Fig. 21*A* was electrically welded and in Fig. 21*B* was gas welded. Identical as described in the metallurgical notch section, accelerated fatigue test did not produce failure in this part either.

These welds have also been made with nonheat-treatable filler metals (or electrodes). Figure 22 shows crack (*b*, from Fig. 21*B*) just ground and polished flat with the surface of the lug. It again indicates that the crack was following a light area, however, not as light as that from Figs. 19 and 20, and Fig. 23 explains why. There are lighter grains (probably high-alloyed and high-carbon ferrite or very low-carbon martensite) around dark martensite. Although exact microhardness checking was impossible because of the size of the light grains, they were much softer than martensitic dark grains. The crack (Fig. 23) followed those light grains which produced weak links in the structure.

Those light grains were produced because of dilution of the lug alloy steel with the very low-carbon filler metal. Figure 22 shows the diluted area just under the toe of the weld.

Notch-Sensitive Alloys

Some alloys such as austenitic stainless steel are known to be notch insensitive. In this case, the calculated geometric stress concentration factor is not a true stress concentration factor. These steels may have

stresses locally relieved by plastic flow and can take quite a high amount of cyclic loads between the start of the fatigue fracture and the actual fatigue failure.

Some alloys may change their notch sensitivity depending on their microstructure or condition. Nonaustenitic steels, for example, increase their notch sensitivity with the increase in hardness or with the increase of the heterogeneity even without the change of hardness level or the ultimate strength.[51]

Titanium and titanium alloys are notch sensitive at least under certain conditions. Fatigue data published by Hanink from Wright Aeronautical, [54–56] produced quite a confusion in the aeronautical engineering circles. He pointed out that notched endurance ratio of titanium alloy may be as low as 0.003.[54] Rem-Cru data,[57] however, is much more optimistic and it gives notch endurance ratio for Rc-130-B as 0.26. In this case, however, the notch root radius was 0.010 in. when Hanink tests were run with the notch root radius of 0.004–0.006 in.

Some metallurgists try to explain the low values found by Hanink as being due to embrittlement produced by contamination of the titanium he used for this experiment, by the interstitial hydrogen. However, it is immaterial to a designer whether this explanation is right or wrong. It may be stated that titanium under certain circumstances (processing) may become very notch sensitive.

Viglione[58] gives some interesting comparative data between spot-welded clad 2024-T3 aluminum alloy, AISI 302 stainless steel and Rc-70 commercially pure titanium. The data below are given for specimens containing seven spot welds arranged normal to the load and for 10×16^6 cycles (Table 3).

For low number of cycles fatigue life (10,000 cycles), the relationship between these three materials was somewhat different. The fatigue strength of Rc-70 was 23% less than that of AISI 302 but 90% greater than that of 2024-T3 aluminum alloy.

On a strength-weight basis, the fatigue strength of steel and aluminum was 57 and 98% of that of titanium

Table 3—Static and Fatigue Properties of Spot Welded 2024-T3, AISI 302 Stainless Steel and Rc-70 Commercially Pure Titanium.[58] Fatigue Stress Ratio = 0.25

Alloy	*Thickness, in.*	*Static strength, lb*	*Fatigue strength 8×10^6 cycles, lb*	*Fatigue ratio*	*Single spot T/S ratio*
Clad 2024-T3	0.050	4,820	850	0.176	0.323
AISI 302	0.047	10,950	1350	0.123	0.839
Rc-70	0.045	16,400	1250	0.076	0.266

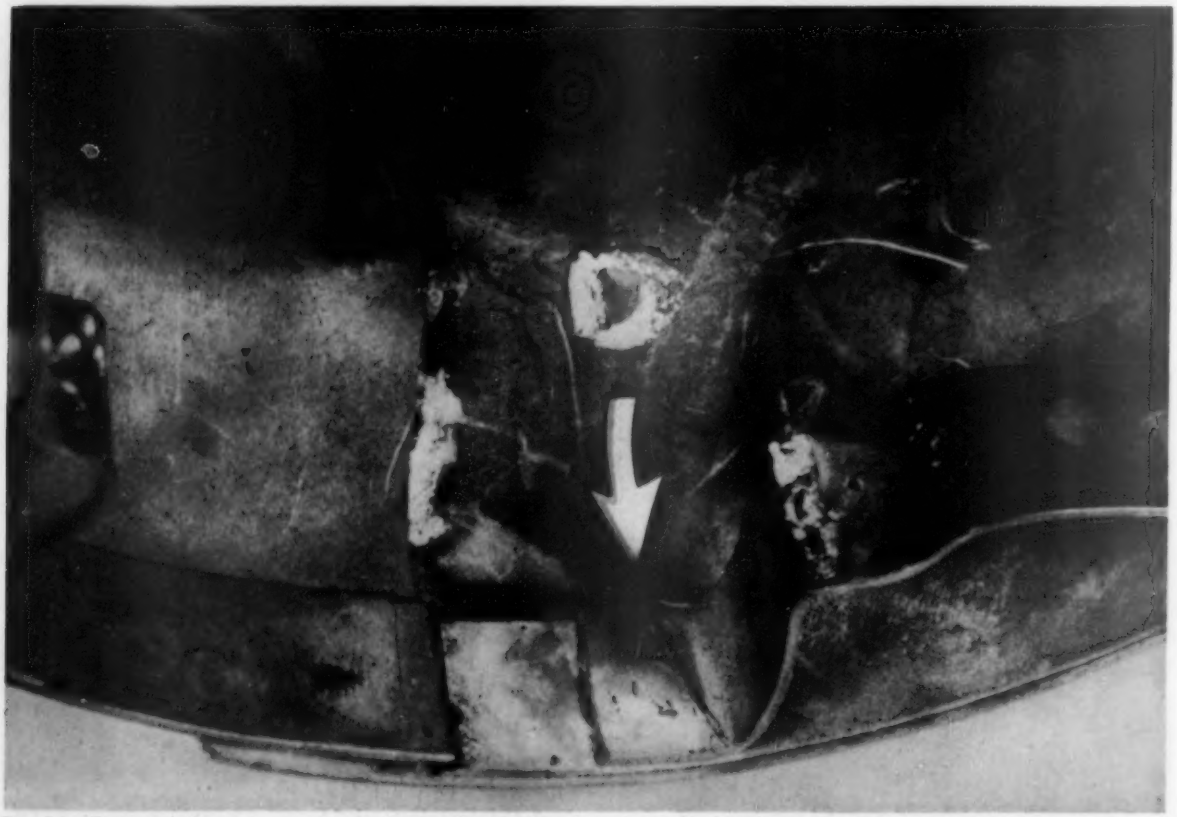


Fig. 24 Fatigue failure of a titanium exhaust collector shroud support. Here, fatigue propagates through the heat-affected zone of the spot weld

for 8×10^6 cycles, respectively. These data give some indication of the relative notch sensitivity of titanium and shows that the design fatigue criteria with titanium must be somewhat different than with other alloys.

To clarify these thoughts further, let us consider a spot-welded exhaust collector shroud support which failed in fatigue (Fig. 24). This shroud was made from commercially pure titanium.

The fatigue failure occurred through the heat-affected zone of the spot weld and was produced by bending loads. Heat-affected zones are usually notch sensitive. As may be seen, the spot itself touched the end of the support curvature and its heat-affected zone was subjected to repeated bending. Besides, during spot welding, this notch sensitivity may have been increased by the absorption of gases which produced brittleness. Lack of deburring the edges of the support probably also contributed to the failure.

It can be stated, then, that weld and weld heat-affected zones should be kept away from curvatures under bending. Edges should be well deburred. This is especially important when designing with notch-sensitive materials.

Miscellaneous

There are some other problems which may be considered when designing a welded joint. Some of those are mentioned below.

Corrosion Fatigue

Corrosion fatigue is a phenomenon in which corrosion (generally pitting) helps to start a fatigue fracture; and, in turn, fatigue stresses accelerate corrosion.

Fatigue corrosion should seriously be taken into account in shore- or ship-based aircraft because of the presence of either the salt water or the salt mist or spray.

S–N Curves—Development Design

An aircraft designer is sometimes faced with a stubborn failing of an assembly or component in fatigue when engaged in development design. In this case it is very desirable to look for advice with an S–N curve of the particular alloy and its particular condition. This is because fatigue curve shapes may vary extensively not only with a particular alloy but also between their different tempers, microstructures and surface conditions.

It should, however, strongly be emphasized that this may give only qualitative and not quantitative information.

Improvement of the Fatigue Life

There are different processes which may increase endurance limit of a material. Some of these processes might also be potential means of improving fatigue life of aircraft components or assemblies.

In particular, the following processes, may increase fatigue limit or fatigue life:

(*a*) Heat treatment: by producing advantageous metallographic structure or surface compressive stresses. Popular stress relieving and normalizing may sometimes be more harmful than useful.[59]

(*b*) Prestressing.

(*c*) Shotpeening and case hardening (carburizing, nitriding, cyaniding, etc.): by introduction of favorable surface residual compressive stresses.

(*d*) Electropolishing: by decreasing the adverse effect of notches as stress concentration.

Brazing

If fatigue data for welded joints are very scarce, available results for brazed joints are almost nonexistent. It does not mean that there are no such data, because brazing is occasionally used for joining critical dynamically loaded aircraft parts such as propellers, helicopter rotor spars, etc. Brazing is also applied more extensively in nonstructural assemblies such as heat exchangers, climatizing, etc. However, these data are not published. Available information is concerned rather with static requirements.[62–77] Some fatigue data concerned mainly with torsional shear in butt bar joints has recently been published.[78]

The evaluation of fatigue strength of brazed joints is still more difficult and complex than that of welds. This is because of many variables which are difficult to eliminate such as: the difference in moduli of elasticity between base and filler metals, gap effect, voids, etc. It has, for instance, been observed that a fatigue crack may start in the silver-base filler metal and propagate into low-alloy steel base metal, although the modulus of elasticity of such a filler metal is much lower than that of steel.

As a result of this, practically every brazed joint is a problem in itself and almost always requires some development work. The design allowables for brazing as given by AN-C-5[59] are apparently very low (15,000 psi shear for silver or copper-based brazed joints) although shear strength as high as 60,000–70,000 psi can be reached. This, however, should not be surprising because of a high number of variables involved.

The author does not intend to go into more details with brazing because this would require another full length paper.

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Although there exists inadequate data on fatigue of welds, the aircraft designer cannot sit and wait for it. In fact, he could not design at all if he had to have his work based on figures only. The designer's background, combined with his intelligence and the ability to analyze and synthesize, must make up for the inadequency of information.

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RADIOGRAPHING 620 MILES OF WELDED PIPELINE

With portable gamma cameras in hand, and a mobile darkroom following, a few experienced radiographers walked 620 miles through brush, scrub and muskeg, over mountains and across permafrost this past summer. They were inspecting welds on the 8-in. products pipeline being built in Alaska and Canada's northwest for the U. S. Army Corps of Engineers.

Built to carry fuel to Alaskan bases, the pipeline starts at Haines, on a sea-arm of the Alaska panhandle, parallels the Alaska Highway for much of its route, and terminates at Fairbanks (Fig. 1). About half the length of the line is in Alaska; the other half in Yukon Territory and northern British Columbia. Enroute, the line spans some majestic and some impossible terrain (Fig. 2).

There were four 2-man teams on the job. Each team was equipped with external pipeline gamma cameras and with a mobile darkroom. A strong source of isotope, iridium 192, was used in each camera. Enroute the teams made some 15,000 radiography shots; used about three miles of film.

Abstracted from *Canadian Isotope Newsletter*, November 1954. Isotope Products Ltd., Oakville, Ont., Canada.

Work started in April with radiographers close on the heels of construction and welding crews. Warm and dry weather let the work progress through late October. Most of the line is now completed. But next summer the crew men will go back for a month or two for final shots.

Laying pipeline in the Arctic involved some unique problems. Often the brush had to be cleared and the pipe was brought in on skids towed by snowplows. Along the route the "right-of-way" generally comprised several inches of swampy muskeg above the permafrost layer.

Burying the pipe presented another set of problems peculiar to the Arctic. In the thawing ground, ditches caved in if left open more than a few hours. In some sections, the buried pipe "floated" up to the surface again as the permafrost heaved it. In such places a recheck of the welds by radiography was often necessary. To anchor the pipe in these locations where they "floated" up, the engineers used 300-lb concrete blocks.

All pipelines are only as secure as their welds. A broken weld in this country, however, would not only

Fig. 1 Pipeline parallels the Alaska Highway for much of its route

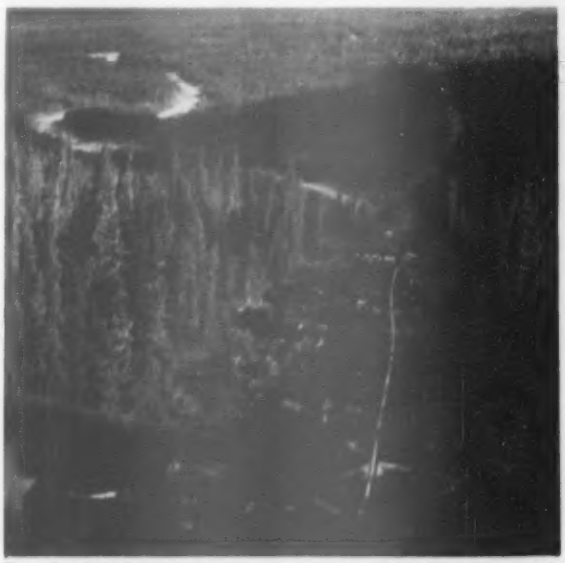

Fig. 2 Pipeline spans some majestic and some impossible country

Fig. 3 Radiographer moving up on a weld, camera in one hand, film in the other

Fig. 4 Radiographing weld at a joint over swampy terrain

be difficult to locate once the pipeline was in operation but repairs would involve moving heavy equipment and men in again. Thus, gamma ray inspection was particularly significant on the Alaska job. The small diameter of the Alaska line and the fact that pipe twists over broken terrain dictated use of an external radiographic operation.

Expert knowledge in radiographic techniques was not enough. Radiographers needed endurance and agility on the Alaska project (see Fig. 3). A 25-lb external pipeline camera, designed for just this type of job, provided sufficient shielding to allow use of a powerful iridium source. At the same time, its lightness and compact size made it possible for a radiographer to inspect welds over miles of pipe that bridged swamp and twisted through tortuous locale.

At each pipe joint the radiographer strapped a film holder around part of the circumference of the weld; opened the camera to expose the gamma radiation; then repeated the process until the whole weld was covered. To radiograph each complete weld took about five minutes.

The gamma cameras and the isotope sources they contained not only had to survive "dunking" in swamp water, but were actually operated under water at times (Fig. 4). On the Iroquois Gas pipeline this summer, parts of that line were under water and radiography was done with the camera completely immersed.

Radiographic film processing was done in mobile darkrooms which followed as close to the crew men as possible. The darkrooms were mounted on heavy-duty

Fig. 5 A mobile darkroom navigating muskeg

$^3/_4$-ton trucks (Fig. 5). Somehow, the vehicles navigated the muskeg even when the going was tough and wet. On each stretch of the line, a two-man crew and one mobile darkroom kept up with the main line welders. A second unit with one or two radiographers worked some distance behind. This following crew radiographed tie-in sections and handled the radiography on difficult river crossings. With iridium 192 and the external pipeline camera, it was possible for one man to handle such jobs alone.

BUTTER CHURN IS WELDED BY INERT-ARC PROCESS

Consumable-electrode inert-gas metal-arc welding is being used in the fabrication of commercial aluminum butter churns by General Dairy Equipment Co., of Minneapolis, Minn., to produce smooth, porosity-free welds. These areas are easy to clean, thus avoiding contamination.

Other factors were also responsible for this company's decision to use this process. Aluminum is easily and efficiently welded by it, welding speed is greatly increased and the weld beads are dense and sound. In many instances, the weld is smooth enough so that costly finishing operations can be eliminated.

Two $^3/_8$-in. thick cast aluminum plates are butt welded, on both sides, with a manually operated, electrode holder, as illustrated in Fig. 1. The operator simply squeezes the trigger of the holder and a consumable wire electrode and shielding argon gas are automatically fed into the weld area. This welded plate is then rolled into a cylindrical shape and welded along its longitudinal seam, forming a shell of half the churn. Two such shells are fabricated for each unit.

[1] Based on a story by the Linde Air Products Co., New York, N. Y.

Fig. 1 Two plates of $^3/_8$-in. cast aluminum are butt welded. A hold-down bar keeps the work firmly in place

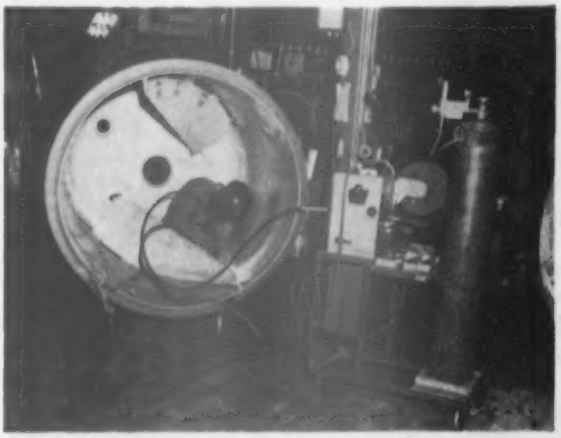

Fig. 3 Vanes are welded into the shell of the churn. This hard-to-get-at area is easily accessible with holder

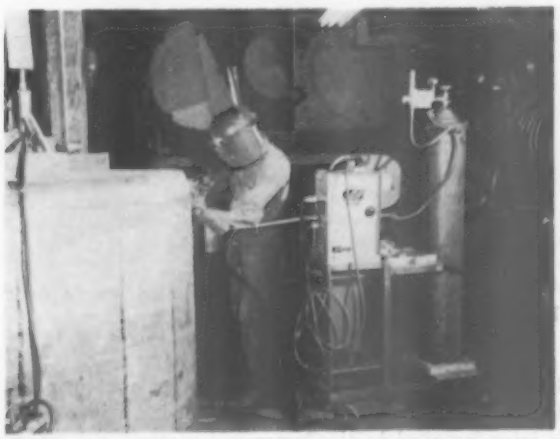

Fig. 2 Gas metal-arc welding joins a cast aluminum head to the end of a rolled and welded cylinder shape

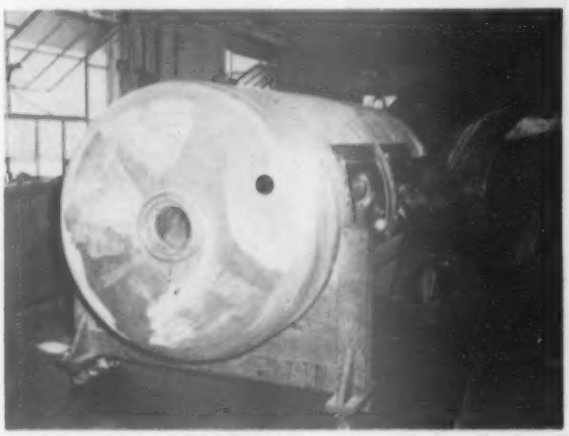

Fig. 4 Butter churn assembled by welding two half-shells together at the open ends

A sand-cast aluminum head is then welded to one end of each cylinder shell, as in Fig. 2. Welding speed is 12–15 ipm. Consumable-electrode inert-arc welding is done smoothly and quickly with a minimum of spatter. Vanes, which are a special feature of the churn, are fillet welded to the inside of the shells, as shown in Fig. 3. The holder is easy to handle in confined areas such as this.

The two cylinders are welded together at the open ends to form a 2000-lb capacity churn. Nonconsumable-electrode inert-arc welding is then used to add aluminum attachments to the vanes and to door frames, as in Fig. 4. The combination of these two inert-gas-shielded welding processes enables the manufacturer to produce a butter churn of greater efficiency and at low cost.

INERT-ARC WELDING USED ON WORLD'S FASTEST TOY JET-ENGINES

A stainless steel jet-engine, the Dyna-Jet, capable of developing 2 hp at 125 mph, is being welded with the inert-gas metal-arc process by the R. S. and G. Co., Brownsburg, Ind., for Curtis Automotive Devices Inc., Bedford, Ind. The powerful midget jets are $21\frac{1}{2}$ in. long, weigh 16 oz and are used to drive model boats, autos and airplanes. One inert-arc welded Dyna-Jet engine has rocketed a miniature plane to a world speed record of 179.03 mph.

The paper-thin Type 321 stainless steel combustion chambers are pressed in two halves (Fig. 1), and then welded together. The edges to be welded have a $\frac{1}{16}$-in. protruding flange the entire $21\frac{1}{2}$-in. length.

The half sections are fitted around a long lead plug or mandrel. A steel holding fixture is then secured around the half section (Fig. 2). A welding operator fuses the flanged edges along one side in approximately three minutes. The fixture is then opened, the part turned and the other half fusion welded. A jet engine is later installed in the larger end of the combustion chamber, and the unit is complete (Fig. 3).

Based on a story by the Linde Air Products Co., New York, N. Y.

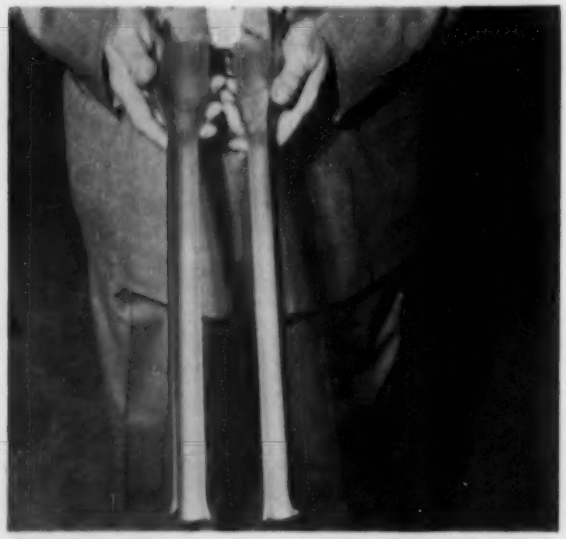

Fig. 1 Two half sections of an 0.018-in. thick stainless steel combustion chamber ready for welding

Fig. 2 Operator completes inert-arc weld in a toy-jet combustion chamber

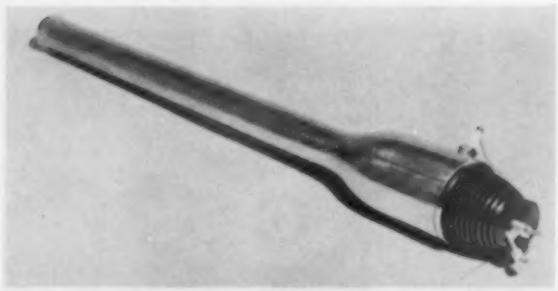

Fig. 3 A finished unit with motor installed weighs only 16 oz, and develops a $4\frac{1}{4}$-lb thrust

Society News

Kansas City in June—
1955 Spring Technical Meeting and Third Welding Show

With the addition of another new feature, the Welding Conference, the total number of major events at Kansas City rises to eight.

In other pages of this issue of The Welding Journal, there are given the complete details of the technical sessions of the National Spring Meeting, the first Annual Meeting of the Society ever to be held in the spring, and the highlights of the exhibits of the third Welding and Allied Industries Exposition.

The decision to set aside part of three days for a series of welding conferences was based on the desire to fill the needs of those who are interested particularly in the practical aspects of welding.

The conference schedule will cover three general topics: (1) "Practical Welding Clinic," on Wednesday, June 8th; (2) "Welded Plastics—A New Field for Welding," on Thursday, June 9th; and (3) "Automation in the Welding Industry," on Friday, June 10th.

The Welding Conference will feature informal panel sessions rather than the reading of papers, although speakers will present short, introductory remarks.

Advance requests for hotel facilities indicate that attendance in Kansas City will be among the largest for any events ever arranged by the Society. The National Spring Meeting will cover four days, from June 7th to 10th, while the Show will be presented from June 8th to 10th.

The Show will be the largest ever held. Companies exhibiting will top the 100-mark for the first time and their displays will be larger, too. A total area of 22,000 sq ft of display space will be used, almost 25% larger than the huge Buffalo Show last year.

A quick checklist of events follows:

National Spring Meeting, with some 41 papers to be read in 13 sessions. Highlights will include the first symposium on the highly controversial topic of welding qualifications.

Annual Meeting, the first ever staged in the spring.

Third Welding and Allied Industries Exposition, the greatest assemblage of welding equipment and accessories ever gathered under one roof, demonstrated under simulated factory conditions.

Welding Conference, three afternoon sessions devoted to welding of plastics, automation and practical welding clinic.

National Sustaining Members Luncheon, the first ever staged.

Annual Banquet, including an address by a speaker of national prominence.

President's Reception, the Society's outstanding social event of the year, presented for the first time in the spring.

Barbecue! The Kansas City Section plays host at a typically regional get-together.

Many additional important events are scheduled: plant tours, sight-seeing trips, events for the ladies and others. Baseball fans will be able to get their first glimpse of the Kansas City Blues in their major league debut.

Air-conditioned hotel rooms are available. All meetings at the Hotel Muehlebach will be held in air-conditioned meeting rooms. The Kansas City Auditorium, where the Welding Conference and the Show will be held, is also air conditioned.

THINGS YOU SHOULD KNOW

At Birmingham, Ala., on February 3rd, the 1954–56 Board of Directors held the second meeting of its term at the Hotel Tutwiler. Actions were taken on various recommendations made by Society officers and members, by the Technical Council, and by the Executive Committee; the latter two groups had held meetings at Birmingham on February 1st and 2nd, respectively.

• Rewording of Article II of the AWS Constitution, which deals with the "Objects" of the Society, was approved. The new wording is being screened by the Constitution and By-Laws Committee and it will be submitted to the membership for ballot at the Annual Business Meeting of the Society at Kansas City, Mo., in the Hotel Muehlebach, on Wednesday, June 8, 1955, between 2:00 and 3:00 P.M. All AWS members will receive copies of this proposed Amendment at least two weeks in advance of the Annual Meeting.

• At the same time and in the same notification to all members, an Amendment to Article III will be proposed. It will consist of allowing companies, corporations, partnerships and organizations, as well as individuals, to hold

Sustaining Membership in our SOCIETY. Approval was given to this recommendation by the Board at its meeting in Chicago on Nov. 4, 1954.

• An extension of one month was granted to all members whose delinquency period would ordinarily expire on March 31, 1955.

• A committee was appointed to draw up a Memorial Resolution for B. H. Allen, past officer and chairman of the Houston Section, and 1953 Chairman of the Houston Arrangements Committee.

• The report of the Special Committee on Awards was studied in connection with proposed rules and wording for the new Meritorious Award Certificates. The Board's recommendations were passed on to the Special Committee for suggested modifications and for early release.

• It was decided to request the SOCIETY's Awards Committee to prepare suitable text for two new certificates for the Henry C. Neitzel National Membership Awards; one for the numerical award and the other for the percentage award. As soon as available, these will be presented to the Sections which, each year, win these awards; copies will also be sent to those Sections which were the winners in past years. The bronze plaques will be exhibited at the National Meeting at the time of award presentations; during the year they will be displayed at National Headquarters.

• As quickly as possible, a uniform pattern of SOCIETY letterhead will be established, as prepared by a professional designer. The Board moved to effect such action within one year. All Sections will be advised in advance so that they will not be ordering excessive stock of their present letterhead. The SOCIETY will provide letterheads for all Sections at no charge. Sections may then imprint their Section name and their Section officers listing thereon, if they so desire.

• Plans are being made to have an AWS membership promotion booth at the Kansas City Welding Show. This activity is under the jurisdiction of the National Membership Committee. Volunteers to devote several hours' time at the booth are hereby called. If you can do so, your help will be greatly appreciated. Show hours are Wednesday, June 8th, noon to 10:00 P.M.; Thursday, June 9th, 10:00 A.M. to 10:00 P.M.; and Friday, June 10th, 10:00 A.M. to 6:00 P.M. Drop a note to J. E. (Ed) Dato, chairman of the National Membership Committee, at National Headquarters.

• The Board ruled that an AWS member may affiliate with any Section of his choice. However, if he does not specify the Section affiliation desired, he is to be automatically assigned to the Section of his mailing address.

• Hereafter, new members whose applications have been accepted at National Headquarters during the month, will be officially enrolled on the first day of the month following. This procedure will make for greater uniformity in record keeping.

Also——

We have, at long last, received the new Section charter certificates from the engravers. Those for the newer Sections will be prepared first. Certificates will also be provided for the older Sections that wish to have them.

Work is starting on the compilation of the biannual Membership Directory. Be sure to send in your card to AWS Headquarters, stating (in print and clearly) your present address and all other data requested. If you fail to do so, we can only repeat the data we now have on file.

The Metals Engineering Division of The American Society of Mechanical Engineers will join with our SOCIETY at the 1956 AWS Spring Technical Meeting. We extend a very cordial welcome to them, feeling sure that both AWS and ASME-MED members will benefit greatly from the activity.

There are many opinions within our SOCIETY regarding the types of member classification AWS should have. Some believe that we should have new classifications in addition to those now available; others prefer fewer than we now have. Some think that a way should be found to provide a classification for "beginners" (a group further advanced than students) at a lower dues rate than the present "Associate Member" scale. And again some others believe that it would be advantageous to combine the "Associate Member" with the "Member" classification; while some are opposed to this suggestion because the present Associate Members would be faced with a dues increase. Then we have members who feel that all members should receive a WELDING HANDBOOK free of charge. Another group believes that we should have available, for those who desire such, a classification at a higher dues rate than the present "Member" scale, providing that particular classification with all of the SOCIETY's publications, including its codes, standards and specifications. It's a "tuffie!"" But, somehow, as it always happens, ways and means eventually will be found to accommodate everyone within each individual's and the SOCIETY's economies. It is the SOCIETY's desire, and its duty, to provide a pattern which serves *all* of its membership, within the range of stable financing. The problem of membership classification, and revisions if required, has been assigned to the official Special Committee on Membership Classification as appointed by the president and approved by the Board of Directors, for continued study and further survey.

We are happy, indeed, to note that, more and more, the AWS Sections are joining with Universities, research organizations and other Societies in the holding of combined meetings, symposiums and conferences on welding, welding engineering and metallurgy in general. This is good. Let's *all* take the welding message to Garcia.

And—let's *all* go to Kansas City!

Joe Magrath

TAC TALKS

AWS Technical Activities

by A. N. Kugler

The Technical Activities Committee —popularly abbreviated *TAC*—is made up of the chairmen of the 26 AWS technical committees and three members-at-large appointed by the president. The technical activities of the AWS are handled by more than 100 committees and subcommittees which are headed up by the TAC. These committees are staffed by over 500 well-qualified men from industry. This membership is drawn from all over the United States and Canada, and there are even some committee members from other countries in the world.

The AWS-ASTM Committee on Filler Metal is a good example to examine closely to get a better perspective of technical activity functions. Its purpose is to prepare specifications for filler metals covering the welding of different metals. This committee operates through nine subcommittees, each one working with a specific group of metals. This committee has issued 12 standard specifications covering such filler metals as carbon and low-alloy steel electrodes and welding rods, stainless steel electrodes and welding rods, copper and copper-alloy filler metals, brazing filler metal, etc. The subcommittees continue to study the

A. N. Kugler is Chairman, Technical Activities Committee and Chief Welding Engineer, Air Reduction Sales Co., a division of Air Reduction Co., Inc.

problems and provide the necessary revisions to keep the specifications up to date.

Other technical committees of AWS prepare recommended practices and similar standards which are intended more for information rather than specific standard details. Examples are Recommended Practices for Resistance Welding, Recommended Practices for Welding Cast Iron and the Recommended Practices for Postweld Heat Treatment of Austenitic Weldments. This latter publication was prepared as a result of widespread discussions on whether or not to stress relieve stainless steels.

The committees comprising the TAC cooperate with the other code-writing bodies and Government agencies for the purpose of insuring uniformity in requirements. These activities, in addition to promoting uniformity, insure good quality in welding, yet avoid adoption of unnecessarily restrictive or prohibitive requirements.

Another of the significant activities of the TAC is the appointment of AWS representatives on committees established by other societies. At the present time there are 27 such representatives serving on committees of the ASA, ASTM, AIEE, API-AGA, National Association for Corrosion Engineers and the IAA, among others.

Safety is a very important aspect of the technical activities of the SOCIETY. Through the efforts of the Committee on Safety Recommendations, manufacturers and users of fluoride-bearing fluxes were brought together, and a uniform caution notice prepared for flux labels. This committee has prepared and issued a pamphlet covering welding and similar work on containers which have held combustibles. This pamphlet has become a universal standard on the subject. When problems arose relative to the possibility of a hazard with thoriated-tungsten electrodes, this committee secured the necessary data to prove that the use of such electrodes was a safe operation. Perhaps the most important phase of the safety activity is the sponsorship by AWS of ASA Sectional Committee Z49, which prepared American Standard Z49.1 Safety in Electric and Gas Welding and Cutting Operations.

All of these technical activities are of great importance to industry since they provide means for establishing industry standards and representing unified thought on common problems. The TAC constantly endeavors to keep aware of industry needs. Several thousand inquiries are received yearly at Headquarters. In a vast majority of cases, published data of the various committees serve to answer these questions. Answers to other inquiries are obtained from the members of appropriate committees. When new problems arise for which there is no published data or existing committees then it becomes the function of TAC to investigate that problem and determine if a committee needs to be formed to cover the subject. Such investigation resulted in the formation of the Committee on Metallizing and the addition of soldering to the work of the Committee on Brazing.

Another topic which is currently under study is the matter of welding plastics.

All of these technical activities are of tremendous value to industry and to individual AWS members. However, members might not be aware of this work were it not for the establishment of Local Section Technical Representatives. These representatives are charged with the responsibility of keeping Section members aware of the work of the TAC. To enable them to carry out this function they are supplied with copies of all standards, recommended practices, etc. as issued. They are urged to display these at all Section meetings. Technical questions arising in the Local Section may be referred to the Technical Representative. If the answer to such questions are not immediately available in the published literature which he has, then he may refer such questions to AWS Headquarters to the Technical Secretary.

It is the hope of THE WELDING JOURNAL and the Technical Activities Committee that this technical activities column—TAC Talks—will become a regular feature. In future issues the work of the individual committees will be discussed. New publications by the committees will be announced together with brief summaries of the contents of such publications. This is just another step in the AWS program of keeping the membership aware of what the National SOCIETY is doing. The members are urged to submit ideas for improving and expanding this column and, in fact, all of the technical activities. Correspondence in this connection should be addressed to the Technical Secretary at SOCIETY Headquarters.

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Celanese Becomes AWS Sustaining Member

Celanese Corporation of America is one of the leading forces in the fiber, chemical and plastics industries, with 14 plants and laboratories located in seven states. The company produces cellulose acetate filament yarn and staple fiber; rayon filament yarn and staple fiber; Fortisan rayon yarn; Arnel, triacetate fiber; organic chemicals; cellulose acetate chemical compounds; cellulose acetate plastic materials; polyester resins and polyethylene film and sheeting. Affiliated companies in Canada, Mexico, Colombia and Venezuela produce similar products.

Joe H. Baker is Sustaining (A) Member Representative.

UNITED STATES TESTING COMPANY, INC.

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QUALIFICATION of Procedures and Operators

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Send for complete Folder

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TECHNICAL PAPERS SESSIONS

1955 NATIONAL SPRING MEETING

JUNE 7-10 • MUEHLEBACH HOTEL, KANSAS CITY, MO.

AWS REGISTRATION

Mezzanine Floor, Muehlebach Hotel

Fees—AWS Members $2.00
Nonmembers $5.00

Monday, June 6
3:00 P.M. to 6:00 P.M.
Tuesday, June 7
8:00 A.M. to 4:00 P.M.
Wednesday, June 8
8:00 A.M. to 4:00 P.M.
Thursday, June 9
8:30 A.M. to 3:00 P.M.
Friday, June 10
8:30 A.M. to 12:30 P.M.

JUNE 7, TUESDAY MORNING

11:00 A.M.—Grand Ballroom—Official Opening Session

Welcoming Address—*J. H. Humberstone, President, AWS*

Digest of the Technical Meeting Papers—*J. J. Chyle, 1st Vice-President, AWS*

JUNE 7, TUESDAY AFTERNOON

Three Simultaneous Sessions

1. INERT ARC WELDING

2:00 P.M.—Grand Ballroom

Chairman—R. W. Tuthill
General Electric Co.
Co-Chairman—J. M. Payne
Butler Manufacturing Co.

A. Some Fundamentals of Inert Gas Arc Welding
by H. C. Ludwig, Westinghouse Electric Corp.

B. Electrode Activation for Inert-Gas-Shielded Arc Welding
by Alexander Lesnewich, Air Reduction Co., Inc., Research Labs.

C. Inert-Gas Welding in the Aircraft Industry
by John M. Thompson, Jr., CONVAIR

2. RESISTANCE WELDING

2:00 P.M.—Colonial Ballroom

Chairman—Jack Ogden
Fisher Body Division
Co-Chairman—J. H. Cooper
The Taylor-Winfield Corp.

A. The Flash Welding of Commercial Molybdenum
by E. F. Nippes and W. H. Chang, Rensselaer Polytechnic Institute

B. The Static and Fatigue Behaviors of Spot-Welded Joints in Titanium
by W. H. Kearns, W. S. Hyler and D. C. Martin, Battelle Memorial Institute

C. Oscillographic Instruments in Spot Welding Quality Control and Maintenance
by G. C. Woodmancy, Boeing Airplane Co.

3. WELDABILITY AND RESEARCH

2:00 P.M.—Junior Ballroom

Chairman—Clarence E. Jackson
Metals Research Laboratories
Co-Chairman—D. De Brunner
Columbian Steel Tank Co.

A. Effect of Welding on Transition Temperature of Nickel Steel Plate
by T. N. Armstrong, International Nickel Co., and W. L. Warner, Watertown Arsenal

B. Initial Characteristics of Chromium-Nickel Steel Weld Metals
by J. Heuschkel, Westinghouse Electric Corp.

C. Properties of Stainless Steel Welds at Ambient and −40° F Temperatures
by V. N. Krivobok, International Nickel Co., and A. Choquet and G. Welter, École Polytechnique

JUNE 8, WEDNESDAY MORNING

Three Simultaneous Sessions

4. INERT ARC WELDING

9:30 A.M.—Grand Ballroom

Chairman—Leslie N. Williams
The Darby Corp.
Co-Chairman—R. C. Becker
International Harvester Co.

A. Carbon-Dioxide-Shielded Consumable-Electrode Arc Welding
by Gilbert R. Rothschild and Harry C. Cook, Air Reduction Co.

B. A Straight Polarity, Inert-Gas Process for Welding Mild Steel
by J. M. Cameron and A. J. Baeslack, Westinghouse Electric Corp.

C. Consumable-Electrode Inert-Arc Spot Welding
by R. L. Hackman, Linde Air Products Co.

5. WELDABILITY AND RESEARCH

9:30 A.M.—Trianon

Chairman—R. E. Somers
Bethlehem Steel Co.
Co-Chairman—A. C. Sluss
Dover Manufacturing Co.

A. Weld-Metal Flaw-Evaluation Studies
by R. S. Ryan and P. J. Rieppel, Battelle Memorial Institute

B. Investigation of the Importance of Quench Aging in ASTM A-300 Steel
by E. F. Nippes, Rensselaer Polytechnic Institute, and W. Fleischmann, Knolls Atomic Power Laboratory

C. Investigation of Weld-Metal Cracking in High-Strength Steels
by R. P. Sopher and P. J. Rieppel, Battelle Memorial Institute, and A. J. Jacobs, Ohio State University

6. STRUCTURES

9:30 A.M.—Junior Ballroom

Chairman—George W. Lamb
Howard, Needles, Tammen & Bergendoff
Co-Chairman—J. A. Hall
Kansas City Structural Steel Co.

A. Static Tests of Arc-Welded Aluminum Alloy Beams
by M. Holt and R. B. Matthiesen, Aluminum Company of America

B. Fabrication of Bridge Plate Girders by Submerged Arc Welding
by J. H. Hoffman, Bethlehem Steel Co., Shipbuilding Div.

C. Maintenance Welding and Cutting Operations on Radioactive Process Equipment
by E. B. LaVelle and J. M. Fox, Jr., General Electric Co.

JUNE 8, WEDNESDAY AFTERNOON

Three Simultaneous Sessions

7. SYMPOSIUM ON QUALIFICATION

2:00 P.M.—Grand Ballroom

Sponsored by Technical Activities Committee.

A. Basic Philosophy
by R. W. Clark, General Electric Co.

B. Application to Arc and Gas Welding
by G. O. Hoglund, Aluminum Company of America

C. Application to Resistance Welding
by J. J. MacKinney, The Budd Co.

D. Application to Brazing Processes
by A. N. Kugler, Air Reduction Co.

E. Application to New Welding Processes
by S. A. Greenberg, American Welding Society

8. AIRCRAFT AND ROCKETRY

2:00 P.M.—Trianon

Chairman—P. G. Parks
Solar Aircraft Co.
Co-Chairman—F. H. Stevenson
Aerojet-General Corp.

A. Fusion Welding Unalloyed Titanium Sheet Without Filler Metal
by A. V. Levy and R. Wickham, Marquardt Aircraft Co.

B. Titanium Alloy Weldability and Correlated Metallurgy
by H. L. Meredith and C. W. Handova, North American Aviation, Inc.

C. Gas Shielded Consumable Electrode Arc Welding of 4130 Steel
by C. R. Sibley and D. R. Kelker, Air Reduction Sales Co.

9. PROCESSES

2:00 P.M.—Junior Ballroom

Chairman—A. E. Wisler
Hughes Tool Co.
Co-Chairman—Lee H. De Wald
National Cylinder Gas Co.

A. Surfacing with Composite Tube Rod
by R. P. Culbertson, Haynes Stellite Co.

B. Evaluation of Fuels and Oxidants for Welding and Associated Processes
by Walter B. Moen and John Campbell, Air Reduction Co., Inc.

C. High-Speed Welding of Light-Gage Material
by R. A. Kubli and T. McElrath, Linde Air Products Co.

JUNE 9, THURSDAY MORNING

Two Simultaneous Sessions

10. PRESSURE VESSELS

9:30 A.M.—Grand Ballroom

Chairman—T. N. Armstrong
The International Nickel Co. Inc.
Co-Chairman—W. J. Snider
Black, Sivalls & Bryson, Inc.

A. Properties and Characteristics of a Quenched and Tempered Steel for Pressure Vessel Construction
by W. D'Orville Doty, United States Steel Corp.

B. Pressure Vessel Design Using High-Strength Quenched and Tempered Steel
by L. P. Zick, Chicago Bridge & Iron Co.

C. Suitability of Quenched and Tempered Steels for Pressure Vessel Construction
by Leon C. Bibber, United States Steel Corp.

11. WELDING ELECTRODES

9:30 A.M.—Junior Ballroom

Chairman—D. C. Smith
Harnischfeger Corp.
Co-Chairman—W. F. Wheeler
National Cylinder Gas Co.

A. Hardenability Evaluation of Welding Electrodes
by Leo M. West, Douglas Aircraft Co.

B. Evaluating the Iron Powder Coated Electrodes for Production Use
by D. B. Howard, ACF Industries, Inc.

C. The Effect of I^2R Heating on Electrode Melting Rate
by J. L. Wilson, G. E. Claussen and C. E. Jackson, Metals Research Labs., Linde Air Products Co.

JUNE 10, FRIDAY MORNING

Two Simultaneous Sessions

12. PIPING AND REACTOR VESSELS

9:30 A.M.—Grand Ballroom

Chairman—R. C. Fitzgerald
Consolidated Gas Electric Light and Power Company of Baltimore
Co-Chairman—B. G. Harrington
Air Reduction Sales Co.

A. Inert-Gas Tungsten Arc Welding of Piping
by H. Thielsch and C. S. Pulliam, Grinnell Co., Inc.

B. Tungsten Inert Arc Stringer Bead Welding of Carbon Steel and Low-Alloy Pipe
by J. Neal, The Fluor Corp.

C. Temper Brittleness of 1 Cr-$^1/_2$ Mo Weld Metal
by W. J. Lester and G. R. Prescott, C. F. Braun & Co.

13. BRAZING

9:30 A.M.—Junior Ballroom

Chairman—J. R. Wirt
Delco Remy Division, GMC
Co-Chairman—Harry Udin
Massachusetts Institute of Technology

A. Lithium Additions to Brazing Alloys
by N. Bredzs and D. A. Canonico, Armour Research Foundation

B. Metallurgical Properties of Silver-Cadmium Zinc Brazing Alloys
by K. M. Weigert, Goldsmith Bros. Smelting & Refining Co.

C. Semi-Automatic Multiple Flame Brazing Larger Brass Electronic Components
by J. W. Weyers and L. E. Mills, General Electric Co.

OTHER ACTIVITIES

JUNE 7, TUESDAY EVENING

6:00 P.M.—President's Reception—Grand Ballroom

8:00 P.M.—National Officers Dinner—Colonial Ballroom

JUNE 8, WEDNESDAY MORNING

11:00 A.M. Tea Room—Board of Directors Meeting

JUNE 8, WEDNESDAY AFTERNOON

2:00 P.M. Tea Room—Annual Business Meeting

JUNE 9, THURSDAY NOON

12:30 P.M. Junior and Grand Ballrooms
Sustaining Members Luncheon

JUNE 9, THURSDAY EVENING

5:00 P.M. Saddle and Sirloin Club
Western Party and Barbecue
(Sponsored by AWS Kansas City Section)
Cocktail Hour, Dinner, Square Dancing and Music
Favors for the Ladies
Sport clothes or western attire suggested!

PLANT VISITS
JUNE 8 and 9

Arrangements have been made for two plant visits during the AWS National Spring Meeting which is to be held in Kansas City, Mo., June 7–10, 1955. The visits are scheduled on successive days so as to allow participation in both trips.

On ***Wednesday morning, 9:00 A.M., June 8th,*** tours will be made of two plants of the Sheffield Steel Division, Armco Steel Corp. The first tour will start at the Safety Department where safety glasses will be picked up and guides assigned. The tour will consist of a visit to the open hearth pit to observe heats being tapped. From there to the blooming mill to watch steel being rolled from a twenty-two inch square bloom down to a five and three quarters by five and three quarters billet. Mechanical scarfing of the bloom at speeds of eighty feet per minute will be observed; also, hand scarfing and secondary conditioning. The short span department will be visited to watch the fabrication of spans. From there, the group will go to the welding shop to see steel mill maintenance welding and submerged arc welding of rolls. Busses will be boarded at the Safety Department and then the scrap yard will be visited to observe cutting operations on normal scrap preparation, and the cutting of large steel skulls ranging in thickness from twenty to forty inches. The visit will be concluded with a tour of the electric furnace plant.

On ***Thursday Morning, 9:00 A.M., June 9th,*** a tour will be made of the Westinghouse Electric Corp. Aviation Gas Turbine Division, and will consist of a briefing on jet engine fabrication and operation of the engine. The tour will consist of a visit to the fabrication areas to see the welding of stainless steel and high temperature alloys. Welding will be resistance spot and seam, inert arc, hand and mechanized, metallic arc. Inert arc welding will be demonstrated in which the parts are welded inside a chamber of inert gas. Mechanized furnace brazing of high temperature alloys will be shown. The viewer will also get an opportunity to see Zyglo and other methods of weld inspection.

LADIES' PROGRAM
JUNE 7, 8 and 9

Many excellent arrangements have been made to date as part of the Ladies' Program during the 1955 Spring Meeting. Coffee will be served each morning at 10:00 A.M. in Parlor A, or Music Room, at the Muehlebach Hotel. On Tuesday, June 7th, there will be a tour of Kansas City with stops at various points of interest. On this tour, the world-famous Country Club Plaza will be visited, as well as the outstanding residential areas.

A luncheon has been arranged for Wednesday, June 8th, at Milleman's Restaurant & Lounge on the Country Club Plaza. After luncheon, the ladies will meet at Helzberg's Diamond Shop where fine facilities will be made available for relaxation or card games.

On Thursday, June 9th, a luncheon will be held at Eddy's Restaurant & Lounge. In addition, the ladies will tour the Donnelly Garment Co., manufacturers of the famous "Nelly Don" garments for women. This company is the largest women's dress house under one roof in the United States.

WELDING CONFERENCES

MUNICIPAL AUDITORIUM

WEDNESDAY, JUNE 8, 3:00 P.M.

Practical Welding Clinic

1. *Maintenance and Repair Welding in the Plant.*
2. *Job Shop Welding Problems.*
3. *Maintenance and Repair Welding of Farm Implements.*

THURSDAY, JUNE 9, 3:00 P.M.

Welded Plastics—A New Field for Welding

1. *Methods and Equipment for Welding Plastics.*
2. *Applications of Welded Polyethylene.*
3. *Applications of Welded Polyvinyl Chlorides.*

FRIDAY, JUNE 10, 1:30 P.M.

Automation in the Welding Industry

1. *How Automatic Control Can Be Applied to Welding.*
2. *Automation in Small Run Production.*
3. *Automation in Large Run Production.*

WELDING SHOW EXHIBITS AND DEMONSTRATIONS

MUNICIPAL AUDITORIUM

Hours of the Exposition	***Wednesday, June 8***	***12:00 Noon to 10:00 P.M.***
	Thursday, June 9	***10:00 A.M. to 10:00 P.M.***
	Friday, June 10	***10:00 A.M. to 6:00 PM.***

Admission by registration.

HIGHLIGHTS OF EXHIBITS AT 1955 WELDING SHOW

MUNICIPAL AUDITORIUM KANSAS CITY, MO.

JUNE 8-10

Advance Glove Mfg. Co.
Booth No. 208
Feature: Advance Terri-Cord welders' gloves designed for light and medium welding.

Air Reduction Sales Co.
Booth Nos. 254 & 255
Demonstration of new No. 48 Duograph gas shape cutting machine. Also, "live" welding demonstrations with Aircomatic Heliwelding, and Aircospot equipment and a new contact electrode.

Alloy Rods Co.
Booth Nos. 227 & 228
Visual demonstration of new all-position iron-powder low-hydrogen electrode-"Atom-Arc." Also, display of Arcaloy, Bronze-Arc, Cut-Arc, Nickel-Arc, Tool-Arc, and Wear-Arc electrodes.

All-State Welding Alloys Co.
Booth No. 205
Display of complete line of All-State alloys and fluxes. In addition, live demonstration of the new automatic All-State "Jet Flux" system.

Aluminum Company of America
Booth Nos. 233 & 234
Demonstration of arc welding methods for aluminum alloys. Display of welded products, panels of samples of Alcoa standard mill products, and latest Alcoa welding literature.

American Manganese Steel Div.
Booth No. 259
Active display of magnetic flux welding as well as new process for automatic hard facing.

American Platinum Works
Booth Nos. 133 & 134
Working demonstration of production silver brazing plus samples of typical jobs performed by these alloys. Also, automatic gas air machine setup to perform production job.

American Wheelabrator & Equipment Corp. **Booth No. 104**
Display of various facets of both wet and dry abrasive blast cleaning process as applied to the brazing, soldering, and welding industry.

Ampower Products Co. **Booth No. 118**
Display of three new portable spot welders. Two have built-in electronic timing controls. One a production model and the other intermittent duty.

Arcair Co. **Booth No. 123**
Live demonstration of gouging with Arcair torch. Also, display of new light duty Model G2 and new extra-heavy duty Model G5.

Arcos Corp. **Booth Nos. 279 & 280**
Display of EB weld insert and process. Also, Arcos filter metals for arc welding: stainless and aluminum wire; stainless, low-hydrogen, and nonferrous coated electrodes.

Aronson Machine Co.
Booth Nos. 120 & 121
New design of pipe turning rolls with wide range of diameter settings and adjustable wheels; speed range 0 to 65 ipm; capacity up to 5000 pounds.

Aro Spotwelders Corp. **Booth No. 276**
Full range of portable spotwelders from lightweight models with tripswitch for intermittent work to watercooled heavy production machines; also, double-barrel and air-hydraulic machines.

Atlas Welding Accessories Co.
Booth No. 122
Display of improved line of Atlas weld-cleaning tools.

Bay State Abrasive Products Co.
Booth Nos. 214 & 215
Demonstration of new weld grinding speed by Bay State's most recent product development, BF-"Blue Flash" weld grinding disc wheels.

Bernard Welding Equipment Co.
Booth No. 229
The latest in the "Bernard-Arc" slag-gas shielded arc-welding process, a live demonstration with gun type equipment. Also, other Bernard welding products.

Burdett Oxygen Co. **Booth No. 130**
Feature: "Burdox Beaver" cutting machine-portable, lightweight, versatile cutting machine; capable of cutting from $^1/_8$" to 4-in. material. Entire unit weighs 16 pounds.

Cam-Lok Division Empire Products, Inc.
Booth No. 126
Display of "Quick-Disconnect" welding electrode holders; both Pug Nose and Straight Nose type; 300-amp capacity; for electrodes up to $^1/_4$ inch.

Cayuga Machine and Fabricating Co., Inc. **Booth No. 267**
Display of Cayuga-matic Warrior, a lightweight, portable manipulator; and Cayuga-matic Seamer, a lightweight, variable speed carriage mounted on its own rail.

Champion Rivet Co. **Booth No. 273**
New line of Champion Croloy electrodes, low-alloy steel electrodes for chromium-molybdenum steels. Also, display of sample welds and graphic presentation of physical properties.

Contour Marker Corp.
Booth Nos. 223 & 224
Exhibit of contour markers, Boyce centering heads, radius markers and pipe flange aligners.

Coyne Cylinder Co. **Booth No. 207**
Display of new Coyne improved acetylene cylinders with curled under bottom for tighter, snugger loads and all welds applied by modern automatic submerged-arc process.

Crucible Steel Co. of America
Booth Nos. 246–249
Display and demonstration of welding techniques for all grades of stainless steel, titanium, zirconium and other metals considered difficult to weld; also, Rexweld hard-surfacing rods.

Dockson Corp. **Booth No. 251**
Exhibit of complete line of gas welding equipment. Also, many items of head and eye protective equipment such as welding helmets, goggles and eye shields.

Eutectic Welding Alloys Corp.
Booth Nos. 243 & 244
"Stump the experts" service sessions. Collections of photographs and welded parts of farm welding repair jobs. Also, demonstration of several new electrodes and five new Eutector fluxes.

Fibre-Metal Products Co.
Booth No. 145
Extensive display of new series of welding helmets, electrode holders, and other accessories, highlighted by new Fiberglas helmets and Weld-Prober machine demonstration.

Frommelt Industries **Booth No. 106**
Major attraction: "SPA-FLA" Spark-Flash portable safety welding shield. A self-supporting shield; for arc flash and spark protection.

Gamma Industries, Inc. **Booth No. 206**
Equipment for radiographing dense materials using radioactive isotopes. Also, instruments designed for use in radiation laboratories and suitable for research workers in metallurgical fields.

General Electric Co.
Booth Nos. 264–266
Feature: G.E.'s new 200 amp liquid-cooled engine-driven welder and a new E-7010 electrode. Also, new line of G-E a-c welders and resistance welding controls.

Goldsmith Bros. Smelting & Refining Co.
Booth No. 131
Silver brazing of dissimilar metals using furnace method to show ease of operation. Complete line of silver brazing alloys and fluxes. Data sheets available.

Harnischfeger Corp.
Booth Nos. 252 & 253
Feature: new P & H model DA-300 HF GW welder. Also, display of new Hydro-Mount, plus Model TI-295, WN 180 and WN-250 welders. Live demonstrations of P & H electrodes and welding positioner.

Hobart Bros. **Booth Nos. 268 & 269**
Representations of complete line of Hobart arc welding equipment, electrodes and accessories, including d-c and a-c welders and automatic and semi-automatic arc welding heads.

Industry & Welding **Booth No. 144**
Graphic presentation of the industrial coverage of "Industry & Welding" (monthly) and "Welding Illustrated" (quarterly). Also, distribution of current issues of both publications.

International Nickel Co., Inc.
Booth Nos. 109–113
Display of Inco welding products, nation-wide service and distribution system, and most effective joining techniques for high nickel alloys and many types of cast iron.

Jackson Products **Booth No. 143**
New Jackson helmets and new series of goggles, besides electrode holders. New fiber-glass safety hats and caps, used singly or with helmets, goggles and eyeshields.

Kasson Die & Motor Corp.
Booth No. 116
Display of new Bren-Weld portable arc welder; portable band saw blade welded with built-in grinder; and all automatic spot welder using toroidal coil.

KSM Products, Inc. **Booth No. 136**
"You try it" demonstration on stud welding. Up to $\frac{1}{2}$-in. studs welded from 110V power source using KSM portable battery unit. Engineers in attendance.

Lincoln Electric Co.
Booth Nos. 239–241
Principal attraction: Idealarc, a universal welding machine combining both a-c and d-c. Unit provides dual control of voltage and amperage on both a-c and d-c.

Linde Air Products Co.
Booth Nos. 218–222, 230–232
Live demonstrations of consumable-electrode inert-gas welding of carbon steel, and a shape-cutting machine with automatic tracer. Also, display of Unionmelt, Sigma and Heliarc equipment.

Liquid Carbonic Corp.
Booth No. 125
Live demonstration of inert arc welding using CO_2 shield on stainless steel and other metals. Also, complete display of gas welding and cutting equipment, and arc welding.

Magnaflux Corp. **Booth No. 139**
Practical demonstration of portable Magnaflux equipment as used for weld inspection. Also, demonstration of dye penetrant inspection method Spotcheck, and fluorescent penetrant inspection, Zyglo.

Marquette Manufacturing Co., Inc.
Booth No. 213
New "Instant Arc" A-C welders with nonconductive "Perma-Shield" cabinets, plus four all new lines of colorful, lightweight "Jet" series oxy-acetylene equipment.

Mc Kay Co. **Booth No. 235**
Display of complete line of mild, special purpose, and stainless steel welding electrodes; emphasis on hard-surfacing, low-hydrogen, and iron-powder welding electrodes.

Metal & Thermit Corp. **Booth No. 250**
Live demonstration of newest Murex electrodes and two new M & T arc welding machines, one an a-c transformer, the other a d-c rectifier. Thermit welding displayed.

Miller Electric Mfg. Co. **Booth No. 258**
Display and live demonstration of several models of arc welding machines.

Modern Engineering Co. **Booth No. 203**
Display of complete line of Meco welding and cutting equipment featuring new oxygen and acetylene two-stage regulators, CO_2 regulators and trip-flint lighter.

Moehlenpah Engineering
Booth No. 278
Resistance welding—a working display of guns and standard welding machines featuring United Welders Inc. and Ar-Ka Engineering equipment.

National Cylinder Gas Co.
Booth Nos. 260–263
Demonstration of an automatic welding process and contact "powdered iron coated" electrodes. Display of oxy-acetylene welding and cutting equipment.

National Torch Tip Co.
Booth No. 274
Display of complete line of cutting, welding and heating tips for acetylene, propane and natural gas, for all makes of equipment. Also, hand cutting torches.

Page Steel and Wire Div.
Booth No. 142
Display of automatic welding wire in various analyses, variety of different types of packaging, and extensive range of gas welding wire.

Pandjiris Weldment Co. **Booth No. 245**
Demonstration of continuous fully automatic "Auto-Weld-Maton" equipment. Also, continuous operation of Pandjiris positioners, turning rolls and RBM welding head manipulators. Additional feature: "Peep-O-Trol."

C. E. Phillips & Co. **Booth No. 107**
Live demonstration of welding cast iron with the metallic arc and using three different electrode types for that purpose.

Porter-Cable Machine Co.
Booth No. 209
Feature: Demonstration of the new Porta-Band Saw for cutting all kinds of ferrous and nonferrous metals in foundries, pattern and welding shops.

Progressive Welder Sales Co.
Booth No. 281
Latest developments in Progressive resistance welding equipment, including

new portable seam welder, new portable gun and new press welder.

Puritan Compressed Gas Corp.
Booth No. 137

General display: Puritan oxygen, acetylene, nitrogen, etc.; Victor's oxyacetylene welding and cutting torches; Hobart's electric welders; welder's helmets, goggles, etc; Tweco's holders and connectors, etc.

J. M. Ragle Industries **Booth No. 135**

Demonstration of Commando rods and display of drill kits, spark lighters, soapstone holders, ferrule crimpers, positioners, welder's caps, chipping hammers and hose and cable machine.

Reid-Avery Co., Inc. **Booth No. 275**

New Raco BW-2 head for submerged arc, open arc or inert arc welding. New activated wire for inert arc welding. Also, low-hydrogen contact electrodes.

Resistance Welder Manufacturers' Assn.
Booth No. 146

Displays of resistance welded products showing the diversification of manufacture possible by the various resistance welding processes. Also, literature published by RWMA will be available.

Robotron Corp. **Booth No. 277**

Featured item: synchronous resistance welding control for welding aluminum to MIL specifications; equipped with precision tap switch control on all features affecting weld quality.

Sellstrom Manufacturing Co.
Booth No. 211

Display of various items of Sellstrom manufacture: welding goggles, welding helmets as well as industrial goggles, Dependon shields, lenses of all descriptions.

A. O. Smith Corp. **Booth No. 256**

Physical demonstration of new C-Omatic process which uses carbon dioxide as shielding gas. Complete display of a-c and d-c power sources, electrodes and accessory line.

Smith Welding Equipment
Booth No. 242

Demonstration of new Silver Star hand cutting torch and Silver Star cutting equipment. Also, a new line of small, low priced regulators.

Square D Co. **Booth No. 212**

Feature: High speed electronic combination controller for operating 1 or 2 welding guns from one transformer. Also, new single phase synchronous controller for aircraft welding.

Stoody Co. **Booth Nos. 169–172**

Principal demonstration: actual welding with bare Stoody alloy wires through the semiautomatic welder. Exhibition of equipment rebuilt and hard-faced with Stoody alloys.

Sylvania Electric Products, Inc.
Booth No. 204

Feature: Sylvania's three tungsten electrodes: Zirtung, Thoriated Tungsten, and Puretung. Also, money-saving tips on Sylvania tungsten electrodes and inert gas welding techniques.

Tempil° Corp. **Booth Nos. 216 & 217**

Display of Tempil° line of temperature indicating materials. Also, demonstration covering application of Tempilsticks,° Tempilaq° and Tempil° pellets temperature indicators. Free literature made available.

Tweco Products Co. **Booth No. 241**

Live demonstrations showing quality of Super-Mel insulation used on Twecotong electrode holders. Also, display and demonstration of complete Tweco line of arc welding accessories.

Uniflex Cable Div. United Metal Craft Co. **Booth No. 115**

Demonstration of two transformers, one equipped with single conductor cables and other with low reactance cables. Also, display of various Uniflex cables showing internal construction.

Unique Turntable & Equipment Corp.
Booth Nos. 147–148

Display of welding lathe and modern single post type of welding positioner. Also, varied series of turning rolls.

United Specialty Corp. **Booth No. 141**

"Weldreel" display: several models of hose reels for the welding industry, as well as the new cable reel.

United Wire & Supply Corp.
Booth No. 117

Feature: the flexibility of low-temperature silver alloy brazing in the induction joining of copper, brass and steel parts, one to another.

Velocity-Power Tool Co.
Booth No. 128

Feature: air-acetylene and air-propane Torch-O-Matics for soldering, plus the Velocity-Power Driver for installing fasteners into steel and concrete.

Vickers Electric Division
Booth Nos. 225 & 226

Display of new production models of Vickers Controlarc, a rectifier welder. Also, demonstration of Vickers rectifiers, operating continuously in boiling water at twice rated load.

Victor Equipment Co.
Booth No. 210

Exhibit of Victor flame cutting and welding equipment, high pressure gas regulators, hardsurfacing alloy rods, blasting nozzles, and latest hand cutting and machine cutting torches.

Wagner Manufacturing Co., Inc.
Booth No. 103

Feature: a simple Universal cutting attachment designed especially to fit any standard acetylene torch for cutting circles, straight lines and straight-line bevels.

Wall Colmonoy Corp. **Booth No. 101**

Operating exhibit demonstrating Colmonoy hard facing alloys, rods, electrodes and powder and the Colmonoy Spraywelder. Also, display of Colmonoy castings, Sweat-on paste and Nicrobras.

Welding Alloys Mfg. Co. **Booth No. 129**

Practical demonstrations in welding; also display of electrode holders, aluminum spool wire, silicon-bronze wire, welding lenses, ground clamps, etc.

Welding Engineer **Booth No. 102**

Principal feature: A number of charts and graphs illustrating the growth of welding; also, sample copies of Welding Engineer and other published matter.

Weldit, Inc. **Booth No. 166**

Main feature: Introduction of new Model 50 Duo-Control regulators. Also, exhibit of complete line of oxyacetylene, gas-air, and LP torches.

Welsh Manufacturing Co.
Booth No. 202

Display of complete line of eye protection devices including welders' goggles, helmets, etc.

Weltronic Co. **Booth No. 105**

Feature: resistance welding controls, high speed gun welder control and special test equipment.

Westinghouse Electric Corp.
Booth Nos. 270–272

Welding demonstration: inert-gas consumable-electrode welding with new West-ing-arc equipment. Brazing demonstration: new 6M brazing alloy. Electrode demonstration: several new Westinghouse electrodes.

Worthington Corp.
Booth Nos. 236–238

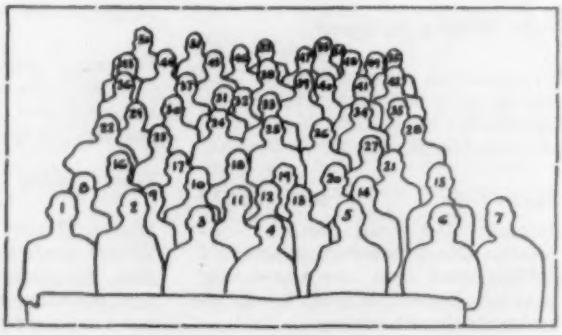
Display of modern precision welding positioners and turning rolls, designed towards the latest concepts of welding industry requirements for automatic and manual welding procedures.

(*Supplementary List of Exhibitors is given on page 495*)

. . . 31 YEARS AGO

There is very little that can compare to the "magic" of an old photograph to brighten the lights on Memory Lane and to provide some precious moments of restful relaxation and pleasant reminiscing. A mighty fine example of this is the rare print recently received at AWS Headquarters through the very kind cooperation and thoughtfulness of Bob Siemer of the Niagara Frontier Section. As shown above, it was taken in Cleveland some 31 years ago, on the occasion of the 1924 Annual Fall Convention of the AMERICAN WELDING SOCIETY. The Staff has been able to identify several of these fine "pioneers" but, unfortunately, there are many more whose names do not come to mind. How many do you recognize? If you can take the time to do so, drop us a line and tell us about it; we would certainly be glad to hear from you at AWS Headquarters.

(1) *W. L. Warner*, (2) *E. H. Ewertz**, (3) *William Spraragen*, (5) *H. H. Dyar*, (6) *G. W. Swan**, (7) *K. Randall**, (10) *W. A. Slack**, (11) *C. A. McCune**, (12) *A. G. Oehler*, (13) *J. W. Meadowcroft*, (15) *S. W. Miller**, (17) *Bob Siemer*, (18) *C. J. Holslag**, (20) *C. W. Bates**, (21) *G. O. Carter*, (25) *R. L. Browne*, (27) *W. R. Boyd*, (28) *B. C. Tracey**, (32) *Louis Fine*, (35) *H. Owens*, (42) *Harold Grow*, (43) *Kenneth Condit*, (45) *H. A. Woofter**, (48) *F. E. Rogers**, (50) *A. M. Candy*, (54) *H. L. Whittemore**.

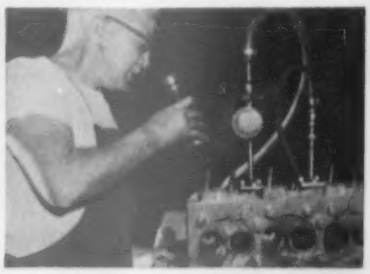


* deceased

Uses Ni-Rod for machinability... Ni-Rod "55" for heavy sections

Cast iron "welding team" simplifies maintenance, cuts costs for Buffalo bus company.

1. Good build-up — Worn valve seat on an engine from one of the 720 busses operated by Niagara Frontier Transit System of Buffalo, N. Y., gets built up with Ni-Rod electrodes. Before being welded, the oil-impregnated casting was degassed in an oven for a half hour at 900°F. Then it was cooled, wire-brushed and preheated to 400°F.



2. Like new with Ni-Rod — Valve seat weld gets close inspection. Then the seat is re-machined. And finally it's pressure-tested. At this point, the men charged with maintenance of this huge bus fleet consider the valve head as good as new. They give a lot of the credit to *the soundness and machinability* of Ni-Rod welds. Mr. W. W. Kunz, who heads the maintenance department says, "Using Ni-Rod and Ni-Rod "55" for repairs on 75 to 100 busses every year gives us a very substantial saving."

3. Chalk one up for Ni-Rod "55", too — A crack that's dangerously close to the cylinder liner gets marked for repair with Ni-Rod's companion electrode, Ni-Rod "55". For stiff sections, like this engine block, and for heavier sections, high phosphorous irons, Ductile Iron, Ni-Resist® and high-strength cast irons, welders choose Ni-Rod "55". Like Ni-Rod, you can often use it *without preheat or postheat.*

If you work with cast iron, you can use this "welding team" profitably in your operation, too.

With Ni-Rod® and Ni-Rod "55"® you can, like this bus company, save worn or damaged cast iron parts that otherwise you'd scrap; and you can also simplify cast iron assembly work.

Ni-Rod and Ni-Rod "55" electrodes are easy to handle. And even welders of limited experience can produce *sound, machinable welds.*

Write today and ask for our FREE FOLDERS ON NI-ROD AND NI-ROD "55".

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street — New York 5, N. Y.

INCO TRADE MARK **Welding Products**
Electrodes • Wires • Fluxes

See Inco's demonstration of NEW welding products.

Visit BOOTH 109 at the Municipal Auditorium Kansas City, June 8-10

WELDING SHOW

Section News and Events

as reported to Catherine O'Leary

INSPECTION AND QUALITY CONTROL

Albuquerque, N. M.—The *Albuquerque* Section met at the Industrial Arts Building, University of N. Mex., on March 18, 1955.

Charles Bowen presented Howard N. Simms (M), director of quality control, Black, Sivalls & Bryson, Inc., Oklahoma City, Okla. Mr. Simms spoke on the problems of welding inspection and quality control, and elaborated on the procedural ramifications involved in quality control considerations. He showed a number of slides correlating such factors as material composition, mass and preheat. The presentation, of particular interest to a number of those present, was well received.

RECTIFIER WELDERS

Fort Wayne, Ind.—The February meeting of the *Anthony Wayne* Section was held on Thursday, February 17th at the Indiana Technical College in Fort Wayne.

About forty-five members and guests were present and were impressed by a talk given by the speaker, Charles H. Jennings (M), engineering manager, Arc Welding Department, Westinghouse Electric Corp., Buffalo, N. Y., and AWS past-president.

Mr. Jennings also gave a very interesting slide-illustrated talk on the "how" and "why" of Selenium Rectifier DC Arc Welders.

QUIZ PROGRAM

Fort Wayne, Ind.—The March 17th dinner meeting of the *Anthony Wayne* Section was held at the Hobby Ranch House in Ft. Wayne.

The program was a membership quiz. The panel was made up of the following AWS members in Ft. Wayne industries: Geo. Laws, Fab Weld Inc.; Carl Gaby, K and G Mfg. Co.; Harry Johnson, Wayne Welding Co.; and Kenneth Zimmerman, American Steel Dredge. Some of the questions had been mailed in by members; others were posed from the floor. The result was a very lively and educational meeting.

DISTORTION CONTROL

Boston, Mass.—The March meeting of the *Boston* Section was held on March 14th at the Westinghouse Auditorium.

After the usual refreshment period, dinner was served to ninety members and guests by Dora Ferguson.

As coffee speaker, William F. Brill of the Ditto Co., Boston Branch, gave an interesting talk on "Selling Problems" outlining some of the difficulties of selling in New England.

The technical speaker of the evening was John Mikulak (M), assistant to the vice-president in charge of manufacturing at the Worthington Corp., Harrison, N. J. His subject, always one of interest, was "Distortion and its Control in Welding." With the aid of slides, Mr. Mikulak first outlined some of the fundamental properties of steel when subjected to heat, and then went on to illustrate how the distortional effects can be minimized in welding by the use of automatic and semiautomatic welding techniques in place of manual welding wherever possible, positioners, clamping methods, and the substitution of bent components and of welded subassemblies for complete assembly for final welding.

FABRICATION

Derby, Conn.—Regular dinner meeting of the *Bridgeport* Section was held on March 17th at Celones Restaurant, Derby, Conn.

Speaker was Floyd I. Newton, secretary and general manager, G. & O. Co., New Haven, Conn. Mr. Newton's subject was on the "Birth and Growth of Small N. E. Industry." Mr. Newton gave a very interesting talk on small business and industry and the importance of impressing upon the people of the community the necessity of working together, not only for the success of the business, but the success of the community as a whole.

Mr. Newton then gave a résumé of the G. & O. Co.'s existence and brought along a sample radiator core which they produce for the automotive industry. Mr. Newton explained to the attending members the procedure for assembling radiator cores and the problems that arise and how they are straightened out.

All the members present enjoyed Mr. Newton's talk very much.

SUBMERGED ARC WELDING

Chicago, Ill.—Well over a hundred members and guests attended the March 18th meeting of the *Chicago* Section. Mr. A. F. Boucher (M), district manager, The Lincoln Electric Co., Detroit, spoke on "Automatic Submerged Arc Welding Application." Mr. Boucher showed many fine examples of the way submerged arc welding has been fitted into the automation programs of the major automobile producers. Many questions from the floor proved the interest of the group.

Before the meeting many members met at Burke's Grill and Restaurant for a fine dinner. From there, they

SECTION MEETING CALENDAR

JUNE 2

NIAGARA FRONTIER Section, Buffalo, N. Y. Annual Outing. Buffalo Launch Club on Grand Island, six miles from Buffalo.

JUNE 11

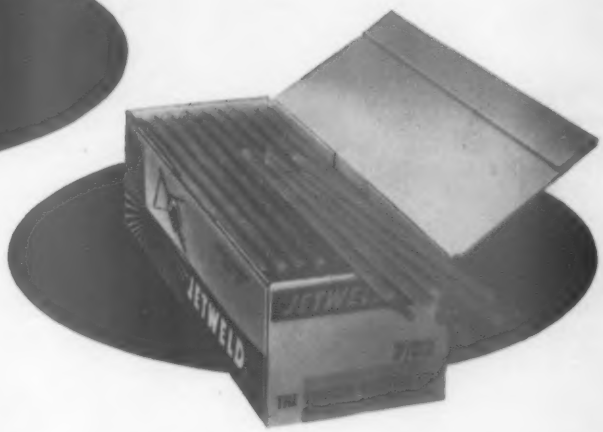
CHICAGO Section. Annual Golf Outing. Nordic Hills.

JUNE 14

DAYTON Section. Annual Picnic.

Editor's Note: Notices to be published in any one given issue must reach Journal office not later than the first of the preceding month. Give full information concerning time, place, topic and speaker for meeting.

Welding industry's
greatest
cost-cutting twins . . .



IDEALARC and JETWELD

Never before has any combination of welder and electrode offered such a cost-saving potential in faster, easier welding. Here's why:

Idealarc for easy, efficient operation . . . first welder to give you *both*
AC AND DC WELDING CURRENT
with Dual Arc Control where you select "soft arc" or "forceful arc" on AC as well as DC
and in addition . . . hot starting on DC as well as AC

Jetweld for high-speed operation . . . first universally adopted iron-powder electrode for
extra-fast welding
high deposition
drag operation

LET LINCOLN DEMONSTRATE HOW YOU CAN PROFIT . . . NOW.
Send for Bulletin 1343. Write . . .

THE LINCOLN ELECTRIC COMPANY
Dept. 1904 • Cleveland 17, Ohio
The World's Largest Manufacturer of Arc Welding Equipment

WITH THE CHICAGO SECTION ON MARCH 18th

Part of the large crowd that attended meeting to hear talk on Submerged Arc Welding Applications

Principal speaker of the evening was A. F. Boucher of The Lincoln Electric Co.

proceeded to the Auditorium, Peoples Gas Light & Coke Co., where they were shown a movie, "Honor Caddie," covering the work that Chick Evans and the Western Golf Association are doing to provide college scholarships for deserving caddies.

Plans for the two concluding meetings of the season include, "Inspection of Welds" by Levi Tarr of the Phillips Petroleum Co. on May 20th, and the annual golf outing at Nordic Hills on June 11th. This latter event is under the direction of Woody Boedecker, Golf Committee Chairman.

HARD SURFACING RODS

Denver, Colo.—H. F. Reid, of the technical office of the McKay Corp., was the speaker at the March 8th meeting of the *Colorado* Section held in the Festival Room of the Oxford Hotel. Mr. Reid's subject, "Let's Face It," dealt with the selection of proper rods for hard surfacing operations. The slides shown with the talk classified rods of different compositions and coatings for best results for both service and economy consideration. Many questions and answers created a lengthy discussion.

Coffee feature was the showing of a very interesting film "Look Into Yesterday"—a story of the building of the Denver & Rio Grande Railroad.

NEW WELDING PROCESS

Cleveland, Ohio—Ninety members and guests of the *Cleveland* Section were present on March 9th in the Mather Room of the Hotel Manger, where they had dinner and were shown a movie, entitled "St. Lawrence Freeway." This fine film was supplied by the Cleveland Electric Illuminating Co., as an after-dinner feature.

Later, one hundred and fifty members and guests gathered together to hear R. J. Keller, assistant director of the Welding Research Laboratory of the A. O. Smith Corp., discuss the newly developed "C-Omatic Welding Process" which is basically an automatic method of welding mild steel and some nonferrous metals using carbon dioxide as a shielding gas.

CONTACT ELECTRODES

Dayton, Ohio—Fifty-two members and guests of the *Dayton* Section met on March 8th at the Dayton Engineers Club to hear Robert M. Losee, welding engineer for the Lincoln Electric Co. Mr. Losee discussed the various types of contact electrodes on the market and how they had been used in Europe for quite a time prior to their recent acceptance in the United States. As pointed out by the speaker, the advantages of these electrodes are a high deposition rate, which permits greater welding speed; ability for the operator to use a drag technique, which helps to reduce fatigue; easy slag removal; good ductility and exceptional shock resistance at low temperatures.

A film entitled "Building a

JOINT MEETING HELD IN DETROIT

Gerald Riley, American Airlines, Inc., was the coffee speaker at the dinner preceding the March 11th joint meeting of the Detroit Section and the Associated Steel Fabricators of Detroit

Carl L. Kreidler, Lehigh Structural Steel, delivered the principal address. His subject was "Welding Structural Steel"

The match test dramatizes an idea—same match and same heat can burn the hand or simply warm it, just as your welding torch or arc welder can, in combination with Eutectic "Low Temperature Welding Alloys," join metals without risk of dangerous overheating, distortion, warping and embrittlement. Write for free booklet "How To Overcome Your Welding Problems." (TIS 2268) Eutectic Welding Alloys Corporation, 40-40 172nd Street, Flushing 58, N. Y.

Character Metal," put out by the International Nickel Co. of Canada, was shown at the beginning of the program.

LADIES NITE

Detroit, Mich.—A Ladies Nite Party has been arranged by the *Detroit* Section for Saturday, May 14, 1955 from 6:00 P.M. to 2:00 A.M., at the Latin Quarter, 3067 East Grand Boulevard, Near Woodward Ave. Program will consist of dinner, door prizes for the ladies, favors, dancing and floor show.

Ticket price after April 30th $18.00 per couple, $9.00 per person. Arrangements are being handled by J. R. Stitt, c/o R. C. Mahon Co., P.O. Box 4666, Detroit 34, Mich.

WELDING STRUCTURAL STEEL

Detroit, Mich.—A joint meeting was held at the Engineering Society of Detroit, March 11, 1955 of the *Detroit* Section and the Associated Steel Fabricators of Detroit. Dinner was held at 6:00 P.M. Mr. Gerald Riley, freight agent for the American Airlines, Inc., was the coffee speaker; his subject was "Air Freight Comes of Age." Approximately 125 members and guests enjoyed a delicious dinner and an interesting talk.

The technical meeting started at 8:00 P.M. and was attended by 250. The principal speaker of the evening was Carl L. Kreidler, Chief Structural Engineer of the Lehigh Structural Steel Co. His subject was "Welding Structural Steel." Mr. Kreidler presented a very fine talk including slides, then concluded with a question period.

It is customary for the Detroit Section to have an added feature at the end of the regular meeting. The special of this evening was a movie of mountain lion hunting called "Outlaw of the Cameron"; it was shown through the courtesy of the State of Tex.

GAS CUTTING

Appleton, Wis.—Mr. Leslie S. McPhee, of the Whiting Corp., Harvey, Ill., was the guest speaker at the February 18th meeting of the *Fox Valley* Section held at the Elks Club.

Mr. McPhee's talk was a general survey of the gas cutting process. He gave a short history of the process and some of the precautions that are necessary to safely use it. He also covered the care of the equipment from the shop standpoint and shop practices. He stressed the versatility of the process in a number of shop applications. In the slides that accompanied the talk he showed a varied number of equipment types.

After the meeting, an arms exhibit was shown by the 84th Div. Military Police Co.

PLANT VISIT

Manitowoc, Wis.—On Friday, March 4th a group of approximately seventy-five members of the *Fox Valley* Section traveled over to the Manitowoc Shipbuilding plant. At the yard the group was taken on a tour of the plant and the new self-unloading boat, the "Detroit Edison." The trip was arranged through the courtesy of Mr. Skatrud, of Manitowoc Shipbuilding.

Launching of the "Detroit Edison," the boat visited by the members of the Fox Valley Section on March 4th

After the tour of the plant, which took approximately two hours, the group enjoyed a dinner at the Wellhoefer's Sea Grill.

OXY-ACETYLENE PROCESSES

Appleton, Wis.—The *Fox Valley* Section met on March 18th at the Elks Club in Appleton. Speaker was A. F. Chouinard of the National Cylinder Gas Co., Chicago. Mr. Chouinard discussed the various oxy-acetylene processes. Mr. Chouinard is AWS district director of West Central District No. 7.

INERT ARC WELDING

Kingsport, Tenn.—The regular monthly meeting of the *Holston Valley* Section convened at 6:30 P.M. on Monday, March 14th at the Kingsport Inn, Kingsport, Tenn. Mr. Frank Crawson, chief service engineer of the Linde Air Products Co., was the speaker. Mr. Crawson discussed automatic inert gas welding of aluminum and stainless steel.

PLANT TOUR

Houston, Tex.—The Houston Section invited the *Sabine Division* to take part in their plant tour at Sheffield Steel Corp.'s Houston Mill on Wednesday, March 23th. This is the largest steel mill between the Canadian Border and the Gulf of Mexico, and between the Mississippi and the Rockies. It is a wholly integrated steel plant including coke

Houston Section and Sabine Division during tour of the Sheffield Steel Corporation's Houston Mill on March 23rd

We all can't get into the ad

but here are four of our family of 25 FLUXINES. 50 years of scientific research enable us to give you the particular FLUXINE you need.

"Complete line of "KOP-R-ARC" coated rods for welding copper and all copper alloys."

NO. 43 FLUXINE —non-glaring for low melting silver solders on stainless steel, iron, inconel, etc. No injurious fumes.

NO. 7 FLUXINE —for welding all types of aluminum, aluminum alloys and Dow Metal.

NO. 4 FLUXINE —for brazing—welding—cast iron with bronze rods. Smooth strong joints.

NO. 88 FLUXINE — concentrated fluid with powerful cleansing—for soft soldering.

Write on company letterhead for chart and generous sample stating which FLUXINE desired.

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545 DEPT. 140

ovens, blast furnace, open-hearth furnaces, electric furnace, blooming mill and finishing mills producing plate, structural shapes, merchant bars, reinforcing steel and wire products such as nails, barb wire, fence and galvanized wire. The tour included dinner in Houston—compliments of Sheffield Steel—short introduction, and guided tour of the plant. Approximately two hundred and fifty members and guests had a most enjoyable time.

AWS ACTIVITIES

Houston, Tex.—On March 23rd the Houston Section officers and directors, and the chairmen of the Sabine, Austin and San Antonio Divisions attended a luncheon meeting. The Section was privileged to have as guests J. H. Humberstone, National President and J. G. Magrath, National Secretary.

Both Mr. Humberstone and Mr. Magrath discussed Section and Society business, plans and prospects.

FLAME STRAIGHTENING

Cumberland, Ind.—A dinner meeting of the *Indiana* Section was held on Friday, February 25th at Buckley's Restaurant. The dinner was followed by a short business meeting. A membership campaign was started with the idea of each member making a sincere attempt to interest at least one man in the AWS during the next sixty days.

The guest speaker was J. R. (Ray) Stitt AWS, research and welding engineer with the R. C. Mahon Co. of Detroit. Mr. Stitt is District Director of AWS District No. 6.

The main topic of the evening was "Flame Straightening," and Mr. Stitt outlined how the Mahon Co. had applied this procedure to the salvage of deformed structural sections. Though the use of slide projection, Mr. Stitt was able to show the members the actual field practice of the flame straightening process and just how it was carried out. The examples ranged from a giant "Coal Loader" practically destroyed by fire to the obtaining of the correct curvature in simple channel sections.

Mr. Stitt also dwelt on the prevention of deformation and cracking in welding fabrication by preventive methods of assemblying and the realization of a few physical theorems of steel under elevated temperatures.

It was the unanimous opinion of the members and guests that this was one of the most informative and useful sessions in the history of the Section.

WELDED STEEL STRUCTURES

Allentown, Pa.—A joint meeting of the *Lehigh Valley* Section with the American Society of Civil Engineers was held on Monday, March 7th, at Walp's Restaurant with fifty-five members and guests at dinner and 110 present to hear Van Rensselaer P. Saxe AWS, a consulting civil and structural engineer of Baltimore, Md., describe various all-welded steel structures. The first such building he said was built in 1927. Since that time, he added, more than 1500 welded structures have been erected, including churches, schools, factory buildings, race track stands, airplane hangers, hospitals and an 18 story apartment building.

ELECTRODES

Allentown, Pa.—"Low Hydrogen and Powder-Coated Electrodes" was the title of a talk given by Dr. Carl Smith, chief metallurgist, Harnischfeger Corp., at the dinner meeting of the *Lehigh Valley* Section held on Monday, February 7th, at Walp's Restaurant.

A coffee talk on "The Labor Outlook" was given by Prof. Herbert Diamond of Lehigh University.

WELDING POSITIONERS

Kansas City, Mo.—The *Kansas City* Section held its March meeting on Thursday, March 10th, at Fred Harvey's Pine Room in the Union Station. Speaker for the meeting was Anthony Pandjiris AWS, president of the Pandjiris Weldment Co. of St. Louis, who gave a very excellent talk on the need for welding positioners in today's very competitive business where production men are looking to cut costs. Mr. Pandjiris accompanied his talk with slides showing the varied types of positioners that are available to handle any type of job, large or small. He gave every one present a basic understanding of the advantages of welding positioners and doing the welding automatically.

ALUMINUM WELDING

Los Angeles, Cal.—A panel discussion on the "Effects of Porosity in Aluminum Welds" was held on March 3rd by the Aircraft and Rocketry Panel of the *Los Angeles* Section. The members met at Swally's Cafe at 7:00 P.M. for dinner followed by the meeting. The panel of experts included Alfred Brothers of Convair, San Diego; James L. Jardene, of Fletcher Aviation, Rosemead, Calif.; John Arthur, of North American

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Aviation, Downey; and Bryon Russell of Airline Welding, Inglewood.

MANUFACTURE OF GASES

Louisville, Ky.—On February 22nd the regular monthly dinner meeting of the *Louisville* Section took place at Korfhage's Tavern. The meeting was very well attended with an equal amount of members and guests. Since the meeting was held on Washington's birthday, and since that particular week was celebrated as "Brotherhood Week," John T. Kenna of the National Conference of Christians and Jews, Inc., was invited to be the coffee speaker. Mr. Kenna handled his subject very interestingly and his talk was well received.

As the technical speaker, L. P. Dobbins, manager of Plant Engineering for the Air Reduction Sales Co., New York, gave a semitechnical talk on the manufacture of gases. He gave a short history of the discovery of the various gases and how they were brought into economic use. Mr. Dobbins described the process used in making gases, the materials used and a general reason for the cost of the various gases. Using liquid nitrogen and liquid oxygen, Mr. Dobbins illustrated some of his points with demonstrations. He finished his talk with several interesting experiments and opened up the meeting for a question and answer period.

ELECTION OF OFFICERS

Baltimore, Md.—*Maryland* Section announces the election of the following officers for the fiscal year:

Chairman—L. H. Matthews, 8727 Stockwell, Baltimore 14, Md.

1st Vice-Chairman—A. Clemens, Jr., 205 E. Gittings Ave., Baltimore 12, Md.

Secretary—R. L. Sibley, Greenspring Ave., Lutherville, Md.

Treasurer—Charles H. Basel, Earlbeck & Landrum, Inc., 1023 Cathedral St., Baltimore 1, Md.

TOOL AND DIE WELDING

Baltimore, Md.—The *Maryland* Section held its regular monthly meeting on Friday, March 18th at the Engineers Club.

The meeting began with the traditional "Pre-heating Session," followed by an excellent dinner. As an after dinner event the motion picture "The Annapolis Story" was shown.

The technical speaker of the evening was Patrick S. Doyen, regional sales manager of the Welding Equipment Supply Co. of Detroit, whose subject was "Tool and Die Welding."

Mr. Doyen's talk, amply illustrated with pictures, thoroughly covered many phases of tool and die welding from small plastic-forming dies to the large ones used in the automotive body plants. The great amount of interest that was stimulated by Mr. Doyen's description of this field of welding was shown by the fact that he was kept on the speakers' stand for approximately one hour after the conclusion of his talk for the purpose of answering the many questions asked by the audience.

MODERN STEELS

Mishawaka, Ind.—The *Michiana* Section held a dinner meeting at the Red Barn Restaurant on March 24th. After a tasty swiss steak dinner and a short business meeting, an illustrated talk on "Modern Steels and Their Weldability" was given by Dr. W. D'Orville Doty, research engineer, welding, United States Steel Corp., Pittsburgh. Dr. Doty's explanation of the subject matter was thorough and was presented in such a way that his audience followed him with close attention.

WELDING QUALIFICATION PROCEDURES

Newark, N. J.—The regular monthly

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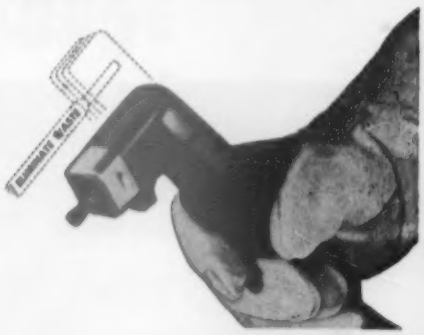

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meeting of the *New Jersey* Section was held on Tuesday, March 15th, at

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Page A-S-10	Page A-S-15-MO	Page-Allegheny A-S-Type 308
Page A-S-17	Page A-S-3½-Nickel	Page-Allegheny A-S-Type 308 ELC
Page A-S-20	Page A-S-6150	Page-Allegheny A-S-Type 309
Page A-S-65	Page A-S-4130	Page-Allegheny A-S-Type 310
		Page-Allegheny A-S-Type 316
		Page-Allegheny A-S-Type 316 ELC
		Page-Allegheny A-S-Type 347
		Page-Allegheny A-S-Type 348
		Page-Allegheny A-S-Type 410
		Page-Allegheny A-S-Type 420
		Page-Allegheny A-S-Type 430
		Page-Allegheny A-S-Type 502

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Mild Steel (GA-50)	C Gas
Low Alloy (GA & GB-60)	Hi-Tensile M
3½% Nickel (GB-65)	3½% Nickel
.55—.65 Carbon	Medium Carbon
.90—1.10 Carbon	High Carbon
Manganese Bronze	Manganese Bronze
Naval Bronze	Naval Bronze
Stainless Steel	According to AWS analysis

Any Page A-S Automatic Grade in 36" Lengths

Bare Electrodes

Armco	Page Armco
Low Carbon	Page "CE"
.13—.18 Carbon	Page "B"
.55—.65 Carbon	Medium Carbon
.90—1.10 Carbon	High Carbon

Metal Spray Wire

Armco	Page Armco
.10 Carbon	#10
.28 Carbon	#25
.40 Carbon	#40
.60 Carbon	#60
.80 Carbon	#80
1.00 Carbon	#100
3½% Nickel	3½% Nickel
Manganese Bronze	Manganese Bronze
Naval Bronze	Naval Bronze
Stainless Steel Metal Spray	According to AWS Analysis

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mild steel electrodes being needed.

A get-together dinner was held in

Mr. Nolmann; everyone was much

meeting of the *New Jersey* Section was held on Tuesday, March 15th, at the Essex House in Newark. Approximately fifty members attended dinner and one hundred and sixty attended the meeting. A short film entitled "What Makes Us Tick" was shown. The film described in detail the workings of the stock market exchange in Wall Street.

Speaker of the evening was A. N. Kugler AWS, chief welding engineer in the Technical Development Department of Air Reduction Sales Co. His well-illustrated talk on welding qualification procedures was a preview of his work on the AWS Subcommittee.

The quiz program was conducted by Mr. Moody of Standard Oil Development.

TITANIUM ALLOYS

New York, N. Y.—"Titanium Alloys" was the subject of the paper presented to the *New York* Section on March 8th. John J. Chyle AWS, of the A. O. Smith Corp. was the speaker and he outlined the difficulties that were first encountered with this metal, difficulties which have been overcome since the metal was first perfected in 1940. Today, titanium alloys are known to have tensile strength up to 200,000 lb. per square inch with welds having equal strength. Welding is now usually done in a vacuum furnace and helium gas is preferred for heavy gage material with argon gas for use for lighter materials.

To eliminate discoloration in the weld deposit, a trailing shield of inert gas, with separate flow, is used. Post heat treatment after cutting helps eliminate tendencies of the metal to crack.

The meeting was held at Schwartz's Restaurant, 54 Broad St., New York City, where dinner was served prior to the technical session.

WELDING ALUMINUM

Buffalo, N. Y.—Charles Bruno AWS, of the Reynolds Aluminum Co., was the guest speaker at the February 28th meeting of the *Niagara Frontier* Section held at the Sheraton Hotel. Mr. Bruno discussed the latest methods of welding aluminum.

Mr. Bruno has had extensive experience in the welding industry. His career began at the Ford Motor Co. He started the first welding school at Ford's Lincoln Plant and later was placed in charge of all welding, machine designing and welding equipment at this plant.

In 1945 Mr. Bruno joined Reynolds Aluminum as head of all welding operations, design and equipment as well as the welding school. In 1947 he transferred to the Technical Service Department and is now in the Products and Applications Department as chief welding engineer.

Slides were used to illustrate Mr. Bruno's address. The necessity of proper cleaning was stressed, and the problems in dealing with the ever present aluminum oxide were illustrated by slides, and discussed.

Mr. Bruno very ably answered the questions put to him by the audience after his talk. He has appeared before many groups throughout the country and is a well qualified authority on the welding of aluminum.

Some of the members and guests who attended the dinner meeting sponsored by North Central Ohio Section on March 4th

PLANT TOUR

Lima, Ohio—Approximately 125 members and guests of the *North Central Ohio* Section attended dinner in the Royal Pine Room of the High Street Market in Lima on March 4th.

Approximately 150 toured the plant of the Baldwin-Lima-Hamilton Corp., Lima Works. Perry Percy of the Construction Division gave a short history of the company. After Mr. Perry's address, the entire group adjourned to the plant and was given guided tours through the entire operation.

Of particular interest was the Beta-Tron exhibit as well as the many displays of the work shown. The Fabricating Shop, Welding Shop, Machine Shop and the Assembly Departments drew the attention of the members and guests attending. The large Type 2400 shovels were examined minutely especially by the members from Marion.

The following new members were introduced at the meeting. Merrill King of Marion and Vern A. Lobdell of Lima.

The Construction Division of Baldwin-Lima-Hamilton at Lima has become the second supporting company in the North Central Ohio Section. Congratulations are due to Vince Woodward for accomplishing this.

FABRICATION OF PIPING

Oakridge, Tenn.—*Northeast Tennessee* Section held its regular monthly meeting on February 28th in the Knights of Columbus Hall in Oakridge. Speaker at the meeting was L. C. McNutt, Benjamin Shaw Co., Wilmington, Del

Mr. McNutt discussed the quality control necessary in the fabrication of carbon and stainless steel piping including base metal requirements, forming techniques and equipment, and welding and heat treatment. The uses of coated electrode, submerged arc, and inert gas welding processes as applicable to pressure piping were discussed in detail. Newer developments in automatic welding equipment and inert gas welding equipment were also included.

SUBMERGED ARC WELDING

Erie, Pa.—Robert (Bob) A. Wilson AWS, head of application engineering and director of training, The Lincoln Electric Co., Cleveland, Ohio, was the guest speaker at the March 16th dinner meeting of the *Northwestern Pennsylvania* Section held at Soudan's Restaurant. Mr. Wilson covered the basic principles of submerged arc welding with special emphasis on the semiautomatic process, pointing out that it is easily adapted to and less costly for production runs than the fully automatic method, mainly because it is not necessary to make fixtures and templates in order to begin production. Also, for irregular shapes, exceptionally large parts, and where fit-up cannot be controlled to less than $^1/_{16}$ in., the semiautomatic process is more practical. With the use of higher currents, penetration is good and the deposition rate is much greater than with gas-shielded arc welding. One of the newer developments is the use of alloy fluxes for strength welds and for hard facing, the alloy being in the flux, with only

mild steel electrodes being needed.

Before the meeting, a thirty-minute film entitled "Steam Power for American Sea Power" was shown through the courtesy of the Babcock and Wilcox Co.

INSPECTION OF WELDS

Olean, N. Y.—The *Olean-Bradford* Section held its regular scheduled meeting on March 14th at the Castle Restaurant.

District director Clarence E. Jackson was present at this meeting and spoke on the merits of membership in the Society. He also answered many questions raised by the audience. Speaker of the evening was R. H. Tobey, Eastman Kodak Co. Mr. Tobey gave an instructive talk on quality and inspection of welds by X-ray with the aid of projection slides. The topic raised a lot of questions which were answered by Mr. Tobey.

FABRICATION OF STRUCTURES

Philadelphia, Pa.—The regular monthly dinner meeting of the *Philadelphia* Section was held on March 21st at the Engineers Club. An excellent discussion on the Economic Fabrication of Welded Structures was given by Carl Kreidler AWS, of the Lehigh Structural Steel Co., Allentown, Pa.

PRESSURE VESSEL STEELS

Pittsburgh, Pa.—The *Pittsburgh* Section met on March 16th in the auditorium of the Mellon Institute of Industrial Research. The subject "Quenched and Tempered Plate Steel for Pressure Vessel Construction" was covered by Leon C. Bibber AWS, chief research engineer-welding, Research and Technology Division, United States Steel Corp., Pittsburgh, Pa. Mr. Bibber described recent laboratory experiments leading up to a large demonstration made at Birmingham, Ala., last summer and known as Operation "T-1." In this operation, eight full-scale pressure vessels made of USS "T-1" Alloy constructional steel, and built by the Chicago Bridge and Iron Co., were tested to destruction by bursting and by impact. The tests were conducted at temperatures in the vicinity of −50° F.

Engineers and research experts participated in the tests before an audience of government and technical code authorities, representatives of the Atomic Energy Commission, Army and Navy Officers, as well as heads of military and civilian aeronautical groups.

The talk was illustrated by colored slides and was followed by a colored motion picture film showing the complete Operation "T-1."

A get-together dinner was held in the Hunt Room of the Hotel Webster Hall.

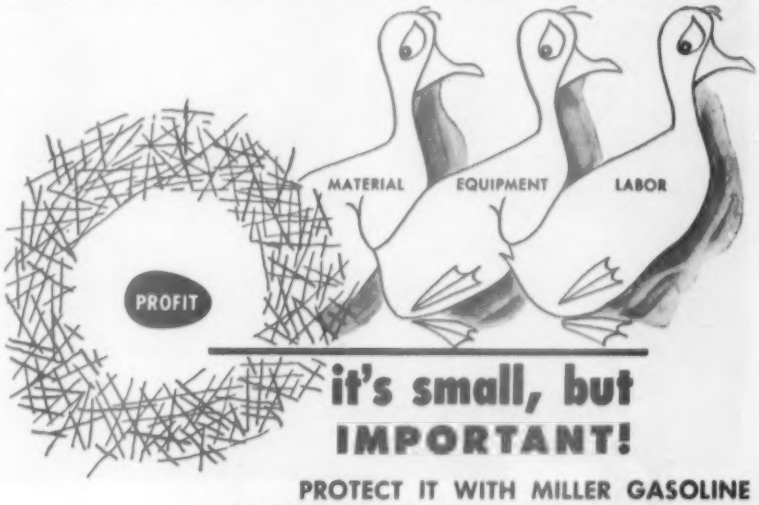
INERT ARC WELDING

Portland, Ore.—The sixth meeting of the 1954–55 season for the *Portland* Section was held Tuesday evening, March 8th, at the Heathman Hotel, Portland, Ore.

A social period and dinner was followed by a very interesting talk by E. C. Nolmann AWS, of Linde Air Products Co. Mr. Nolmann's talk was titled "Inert-Gas Metal-Arc Welding of Carbon Steels." An excellent coverage of this subject was made by Mr. Nolmann; everyone was much interested in what he had to say, since his subject dealt with the latest developments in the welding field.

QUIZ NITE

Saginaw, Mich.—The annual Quiz Nite of the *Saginaw Valley* Section was held on March 10th at the High Life Inn in Saginaw. The dinner meeting was attended by 60 members and guests. Jim Quigley AWS, of Lincoln Electric Co., Bay City, was head quiz master. A number of interesting questions were asked from the floor and answered by other members of the audience. Cash award



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was given to those giving the correct answers.

Before the meeting, a motion picture entitled "Sand & Flame" showing the manufacture of auto glass was shown through the courtesy of General Motors.

INSPECTION TECHNIQUES

St. Louis, Mo.—A joint meeting of the *St. Louis* Section with the Engineers Club and N.A.C.E. was held on January 20th at the Engineers Club with an attendance of 210. Speaker was Lew Gilbert [illegible], executive editor of Industry and Welding. Mr. Gilbert's talk on Inspection Techniques reviewed most of the modern nondestructive methods of examining welds, including visual inspection, radiographic methods, magnaflux, dye colored penetrants, and ultrasonic testing. He pointed out the advantages and disadvantages of the various processes, and recommended which might be the best for a certain application.

Those attending were thoroughly convinced that Mr. Gilbert knows his field very well, and that he is familiar with the practical aspects of it, as well as the theoretical. He has had a great deal of background experience in the welding industry, and his talk was down-to-earth, and of value to the welder and inspector, as well as those concerned with the theory of weld inspection. Mr. Gilbert has a good sense of humor, and his talk was enjoyed very much by the audience.

WELDING DEVELOPMENTS

Alviso, Calif.—The February meeting of the *Santa Clara Valley* Section was held on March 1st at Vahl's Club, Alviso. Speaker was Fortune Masdeo [illegible], welding engineer, Hiller Helicopters, Palo Alto. Mr. Masdeo is second vice-chairman of the Santa Clara Valley Section. "What's New in Welding" was the title of Mr. Masdeo's illustrated discussion.

ELECTRODES

Miami, Fla.—The *South Florida* Section held its March meeting on the 16th at the Builders Exchange Building in Miami. Dinner guest and speaker was (Bud) Clemens of Arcrods Inc., Sparrows Point, Md. Mr. Clemens gave a very detailed talk on mild steel and low-hydrogen electrodes which was illustrated by slides and followed by a question and answer period.

MAGNETIC FLUX WELDING

Syracuse, N. Y.—The regular monthly meeting of the *Syracuse* Section was held on March 9th at the Hotel Onondaga.

The technical speaker, M. W. Barron AWS, American Brake Shoe Co., Mahwah, N. J., gave a very interesting and informative talk on their new development, the Magnetic Flux Welder. Mr. Barron explained that the chief "bugs" in the machine were centered around the development of fluxes which would give good coverage, but would not cause porosity or other welding flaws, such as undercutting. The balancing of the constituents of flux, to give good quality, is a problem which is being continually investigated by them.

They feel that the increase in the amount of metal deposited per hour employing this process is enough of an advantage to offset the slight disadvantages encountered at this time. They are able to produce higher tensile, yield and elongation values from test plates where this process is employed.

The slides which accompanied the talk illustrated Mr. Barron's points about test results and welding currents used, and included a schematic diagram of the welder itself.

A question and answer period was held following the meeting. The members asked many questions pertinent to the using of such a machine in production and in the maintenance shop.

The coffee speaker, James Lampman, is supervisor of the Organic Chemistry Section of the Materials and Process Laboratory of the General Electric Co., Syracuse, N. Y.

Mr. Lampman's subject was plastics, and he gave a very glowing picture of the progress expected in the very near future. He expected that automobiles with plastic bodies will be in production soon, and felt that joining them by welding processes will need the technical know-how and the help of the welding industry to further their progress.

STAINLESS STEELS

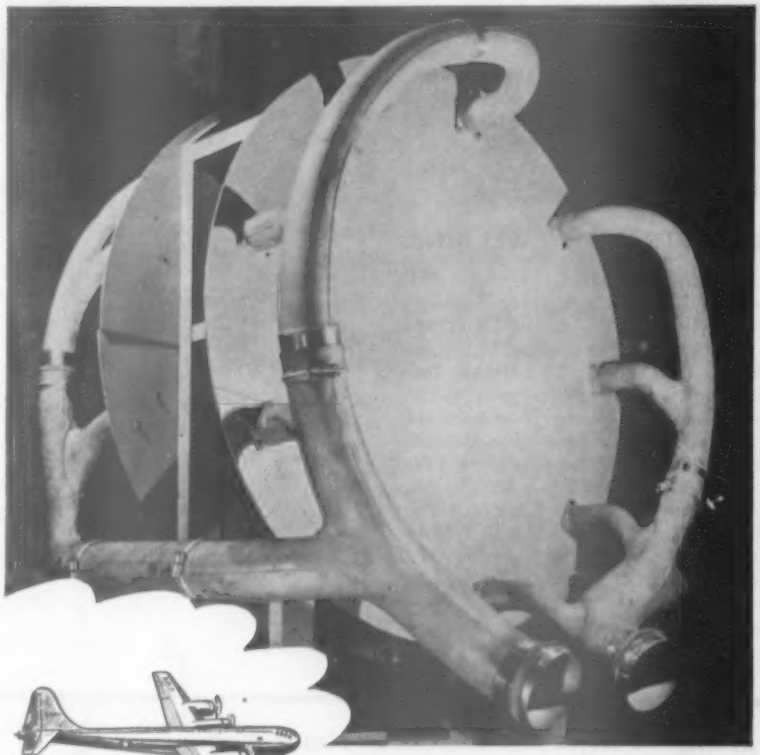
Sheffield, Ala.—Welding of Stainless Steels was covered by Harry Reid, Jr. AWS, of the McKay Co., York, Pa., at the February 24th meeting of the *Tri-Cities* Section held in the TVA auditorium.

AIRCRAFT WELDING

Tucson, Ariz.—The *Tucson* Section held its regular meeting on March 24th at Randolph Municipal Club House.

National President J. H. Humberstone, National Secretary J. G. Magrath, and Ralph Smith, district director, spoke on the various activities of the Society at the business meeting which took place before the

ARCOS FOR FINEST QUALITY WELDS



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technical meeting.

Guest speaker for the evening was Edward J. Meyer, chief process engineer for Hughes Aircraft Co. in Tucson. Mr. Meyer's talk was divided into two parts. He spoke first on aircraft requirements for welders and exhibited samples of aircraft welding. The second part of his talk was devoted to how to achieve the necessary success to meet aircraft specifications from the metallurgical standpoint. A very enthusiastic discussion was initiated after the speaker explained the metallurgy of a weldment.

SEMIAUTOMATIC WELDING

Washington, D. C.—One of the outstanding programs of the *Washington* Section, with 77 guests for dinner and 111 at the meeting, took place on March 1st at O'Donnell's Restaurant. The reason for the big turnout was to hear Robert A. (Bob) Wilson, of the Application Engineering Department, Lincoln Electric Co., Cleveland, Ohio. Mr. Wilson's talk on "Where, When and How to Use Semiautomatic Welding" was illustrated with a number of slides all of which proved very interesting. Mr. Wilson included in his discussion the most recent developments in the use of alloy fluxes for strength welds and for hard surfacing.

NON-DESTRUCTIVE TESTING

Springfield, Mass.—A joint meeting of the *Western Massachusetts* Section with the Connecticut Valley Chapter of the Society for Non-Destructive Testing took place on March 8th at Blake's Restaurant. The technical speaker was Sidney Low, supervising engineer, Research and Development Laboratory, The Chapman Valve Mfg. Co. in Indian Orchard, Mass. Mr. Low's subject was on Non-Destructive Testing in Welding. Mr. Low covered his subject in detail and showed slides of the method used in testing welds and the proper method of repair welds. His talk was highly educational.

NEWLY ELECTED OFFICERS

Springfield, Mass.—The following officers have been elected by the *Western Massachusetts* Section for the fiscal year:

Chairman—Arthur Mission, 28 LaBelle St., West Springfield, Mass.

1st Vice-Chairman—Walter A. Gutowski, 6 Clinton Ave., Westfield, Mass.

Secretary—Leon W. Jaeger, 2040 Columbus Ave., P. O. Box 738, Springfield, Mass.

Treasurer—R. Frederick Fountain, North Road, Hampden, Mass.

Chairman Membership Comm.—Norman Randall, 89 Lehigh St., Springfield, Mass.

Chairman Program Comm.—Victor Bissonnette, 201 Pasco Rd., Indian Orchard, Mass.

Technical Representative—C. A. Keyser, Amherst, Mass.

WORCESTER MEETINGS

Worcester, Mass.—LaMotte Grover, welding engineer, Air Reduction Sales Co., New York, gave a semitechnical talk on Advancement in Structural Welding at the January 3rd meeting of the *Worcester* Section held at the Tower House.

Jack Douglas, Linde Air Products Co., gave a discussion of Inert Arc Processes and Equipment at the February 7th meeting.

A. N. Kugler, chief welding engineer, Air Reduction Sales Co., New York, discussed welding as used in maintenance at the March 7th meeting.

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Putnam, Roy F. (B)
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Goodman, Daniel J. (B)
Rye, Thorstein O. (C)
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Lynch, D. L. (C)
Miller, George T. (C)
Schwartz, Wm. M. (B)

COLORADO

Hogan, Daniel M. (B)

COLUMBUS

Belter, Everett H. (C)
Burwell, Maurel R. (C)
Palmer, John R. (D)

DETROIT

Hoernschemeyer, Frank H. (C)
Rangus, A. (B)

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Ayres, J. E. (B)
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Barnett, Frank J., Jr. (B)
Bentin, Henry H. (C)
Billimek, Reno J. (B)
Boldt, Albert (C)
Boyd, James H. (C)
Bradford, Russell A. (B)
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DeRossett, E. E. (B)
Ellis, Emil R. (B)
Engels, Franz (B)
Eschenburg, Gus C. (B)
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Frazier, C. W. (C)
Furlong, F. B. (C)
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Gordon, Robert B. (C)
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Hare, Milam P. (C)
Heimer, Leonard (B)
Henson, E. E. (B)
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Hornbeck, Calvin W. (B)
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Zigmond, Alfred (C)

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Milek, W. A., Jr. (C)

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Weldon, James W. (B)
Williams, Leslie N. (C)

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Frost, Marion Edward (C)

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Bayer, Norbert (C)
Koch, Ralph L. (C)
Mortensen, Howard L. (C)

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Ives, Loyal T. (C)
Killfoile, Daniel J. (C)
Kreider, David B. (B)
Romaine, Thomas (C)

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Lockwood, Herman L. (C)

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Zino, Albert C. (B)

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Gill, John K. (B)
Goodwine, Paul (C)
Greetham, Donald F. (C)
Wright, Glenn Allen (C)

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Heranen, E. E. (C)
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Myers, Robert (C)
Ogden, Paul (C)
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Schlatter, Herman (B)
Schmidt, Walter F. (C)
Sigurdson, Grimur (C)
Stryz, Anthony (C)
Waldman, Samuel (C)

TUCSON

Dilsaver, Theodore (C)
Huerta, Ruben A. (C)
Reynolds, Virgil E. (C)

WASHINGTON

Hill, Joe H. (C)
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Potter, Edgar (B)
Rose, Alejandro Saloschin (B)

Members Reclassified

During the Month of February

CHICAGO

De Santo, Joseph (C to B)
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Plaskon, John (C to B)

(Continued on page 524)

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ABSTRACTS OF CURRENT PATENTS

prepared by V. L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington 25, D. C.

2,703,357—Welding Electrode and Means for Ejecting Same From Holder—Preston M. Hall, Roger Heights, Md.

Hall's patent is on an electrode for a resistance type welding machine and the electrode has a tapered end which fits into the holder of the welding machine. The electrode also has a peripheral groove in one portion thereof which receives a ring therein. This ring is positioned adjacent the welding machine and is made of a metal which is appreciably harder and tougher than the body of the electrode to provide a member for engagement with a tool for use in ejecting the electrode from the holder.

2,703,383—Heat Control Circuit for Electric Welding—Ernest G. Anger, Wauwatosa, Wis., assignor to Square D Co., Detroit, Mich., a corporation of Michigan.

This patent related to a control circuit for electronic welders and the control includes a pair of electronic tubes connected in inverse parallel and each having an anode, a cathode, and a control grid. Means apply an alternating voltage between the anodes and cathodes of the tubes, while other means supply alternating voltage between the cathodes and control grids of the different tubes, which grid voltages are 180° out of phase with each other. Other special control means are present in the circuit for making the control grids negative with respect to the cathodes when the other means supplying voltage to the control grids tend to make them positive with respect to the cathodes.

2,703,835—Arc Welding Apparatus and Method—Albert T. Douglas, Kansas City, Mo.

A method of welding a metal washer to a generally horizontal surface of a metal body at a particular point is disclosed in this patent. The method comprises the steps of establishing a potential difference between the body and the welding electrode, positioning an insulating panel against the body to cover a portion of the generally horizontal surface adjacent to but exposing the point at which the weld is to be effected, and positioning the washer on the insulator. The end of the electrode is inserted into the hole in the washer and the electrode is shifted laterally toward the particular point at which the weld is effected while maintaining the end of the electrode substantially against the insulation panel to cause the washer to slide along the panel and cause the electrode and washer to move into engagement with the surface of the body when they reach the desired point at which welding action is effected.

2,703,978—Apparatus for Testing Welded Tubing Seams—Bruce L. Baxter, Louisville, Ky., assignor to Reynolds Metals Co., Richmond Va., a corporation of Delaware.

This tester uses a probe gas under pressure for continuously testing a weld seam in a continuously moving tubing. The apparatus comprises an inlet nozzle deposed over the seam for applying high-pressure gas thereto, and an exhaust conduit having a longitudinal slot adapted to be disposed within the tubing with the slot beneath the seam. Sealing means surround the nozzle and frictionally engage the tubing to seal the high-pressure gas directed through the nozzle while other sealing means surround the exhaust slot for engaging the exhaust conduit and the tubing in gas tight relationship. Other means are provided in the exhaust conduit for indicating the presence of any probe gas therein.

2,703,997—Means for and Method of Cold Pressure Welding—Anthony Bagnold Sowter, Wembley, England, assignor to The General Electric Co. Ltd., London, England.

Sowter's patent is on a composite method of pressure welding and forging comprising placing a disk upon a plate or the like wherein both members are made of a pressure weldable metal, supporting the plate and applying a pressure to effect indentations of the disk metal at a plurality of angularly spaced segmental and strip-like welding areas spaced from the outer edge of the disk but coinciding with the circumference of a circle concentric with the disk. The pressure application is continued in the said areas while pressure is applied to the metal of the disk lying between the circle of the welding areas and the edge of the disk. This embeds the edge of the disk into the plate flush with the surface thereof to leave the metal of the disk within the circular welding area thereof raised above the plate.

2,703,998—Method of Pressure Welding — Anthony Bagnold Sowter, Wembley, England, assignor to The General Electric Co. Ltd., London, England.

This second pressure welding method of Sowter's also relates to securing two members made of cold pressure weldable material together and in this instance a relatively small member is secured to a larger metal member. Uncomtaminated metallic surfaces are provided on the areas of contact to be joined and the first member is suported by a surface extending beyond its periphery and the second and larger member is placed upon the first member with the cleaned areas in contacting relation. A pressure is applied without the use of any external welding heat to a substantially closed strip-like welding area of the second member which pressure is equally spaced from the periphery of the first member so that an indentation at the area is produced and creates an interfacial metal flow conductive to pressure welding of the members at such area. The pressure is continued to the strip-like area and additional pressure is applied to the metal adjacent thereto and extending beyond the periphery of the first member to embed the first member into and flush with the second member and to complete a pressure weld of the members at such area.

2,704,317—Sheathed Welding Electrode for Welding of Intergranular Corrosion Resistant Stainless Steel—Werner Hummitzsch, Hamm, Germany, and Franz Ablasser, Kapfenberg, Austria, assignors to Gebr. Bohler and Co., Aktiengesellschaft, Vienna, Austria.

A sheathed electrode for the production of hot-crack resistant welds on corrosion resistant chrome-nickel steels is disclosed by this patent. The electrode has a special composition including a core wire made from carbon up to 0.15%, silicon up to 0.50%, manganese 0.6 to 4%, chromium 14 to 26%, nickel 2 to 14%, and niobium 0.9 to 10%. The niobium is present in relation to the manganese in the approximate ratio of 3 to 2. The remainder of the electrode is iron, and a sheath is provided around the electrode made from lime, fluorspar and silicates.

2,704,707—Method of Salvaging Brazed Assemblies—Milton B. Lemeska, Lancaster, Pa., assignor to Radio Corp. of America a corporation of Delaware.

This patent related to a method of salvaging brazed together metal parts and comprises the steps of immersing the parts in mercury vapor to dissolve the brazing metals and to separate the parts from one another.

2,704,883—Method of Welding Carbon Steel to Stainless Steel—Jack L. Hamilton, Matti H. Pakkala and Raymond Smith, Pittsburgh, Pa., assignors to United States Steel Corp., a corporation of New Jersey.

This patent relates to the production of clad metal composed of a base of plain carbon steel and a surface layer of stainless steel welded thereto. The method includes cleaning all of the scale from the surface of the plain steel base and subjecting the scale free surface to the action of nitric acid at a temperature of from 140 to 180° F to render the surface resistant to oxidation. Before the base dries all traces of smudge formed thereon are removed and the base is washed and immediately dried. The scale is removed from the surface of the stainless steel cladding piece and it is superimposed on the base with the cleaned surfaces abutted. The base and stainless steel material are heated to a welding temperature and they are hot rolled to weld them together.

2,704,884—Method of Forming Hard Facing Surfaces—Glenn R. Ingels, Houston, Texas.

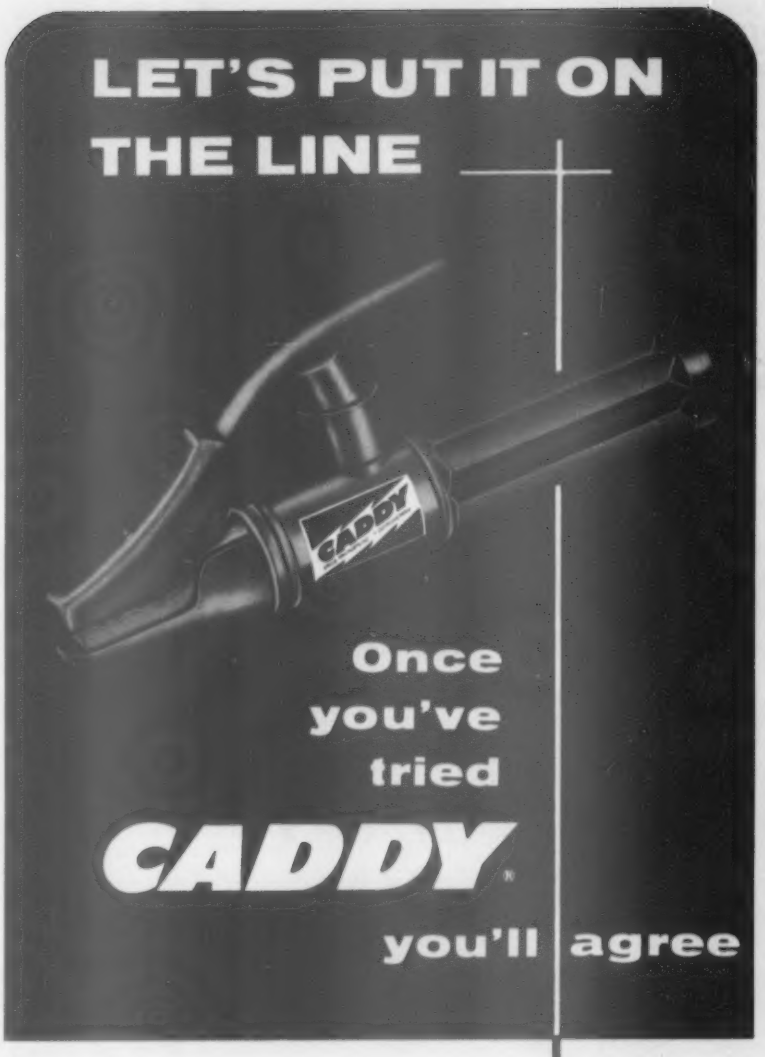
A process of making a unitary hard-faced article from an envelope of binder material having hard facing particles therein surrounding a base member is disclosed in the patent. The base member is initially a hard-faced article and has a wear resistant surface on one side and has exposed binder material on the other sides. The method comprises applying heat to the wear resistant surface of the hard-faced article until such side is in a state of substantial plasticity, which heating is effected without any substantial melting of the binder material carrying surfaces of the hard-faced article. Such heated side is worked while in a state of substantial plasticity to provide intimate and bonding contact with the hard facing particles and to substantially expose such particles on such side of the resultant hard-faced article.

Supplementary List of Exhibitors at 1955 Welding Show

In addition to the organizations whose names appear in the featured presentation on pages 471 to 473, the following companies will exhibit at the 1955 Welding Show in Kansas City on June 8th to 10th:

Ames Spot Welder Co., Inc.	Booth 151
Balteau Electric Corp.	Booth 150
Vacu-Blast Co., Inc.	Booth 152

This information was not available at the time that the principal list was prepared and processed for publication. Also, arrangements are now being made with several other organizations to exhibit at the Show.



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WELDING ARCS NEWS

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G-E MG WELDERS—200, 300, and 400 amps: provide unique magnetic interactor to minimize popouts and assure a steady, forceful arc.

Tests show how G-E rectifier welders provide a stable, easily handled arc, even on difficult vertical welding

FULL-TIME arc-force control virtually eliminates short-arc sticking

Faster, easier welding and improved arc stability . . . these are two important advantages you get with the new General Electric rectifier welder. And with G-E **full-time** arc-force control, you can match your job with a soft or deep-digging arc . . . at the flick of a switch.

Soft arcs are desirable for many jobs. But short-arc work needs a forceful and deep-penetrating arc.

WHY YOU NEED arc-force control is shown in G-E laboratory research: As you weld, metal drops pass from the electrode to the work — causing frequent short circuits. Without arc force, the drops cool, and if you are using a short arc—the electrode will likely freeze to the job.

OSCILLOGRAPHIC PROOF (next column) shows how G-E arc-force control provides a powerful, split-second surge of current to blast the metal drops away—allowing you to bear down on the arc. Without arc force (lower graph), short circuits are long and at low amperage. The drops cool, causing sticking in short-arc welding.

CONTINUOUS OPERATION is an exclusive feature of G-E arc-force control. Since the capacitor design is self-protecting, there is no thermostat to cut out the arc force just when you need it most. G-E **full-time** arc-force is always ready to stabilize the arc and give deep penetration.

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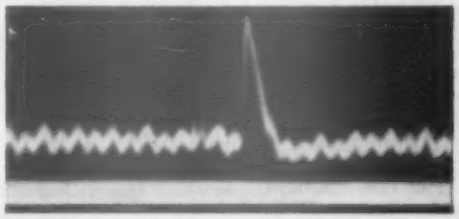
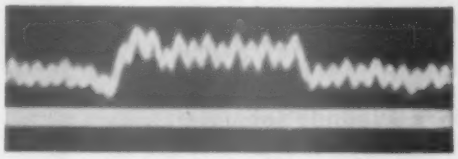


G-E arc-force blasts away short circuit



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- ☐ GEA-6243, G-E AC Welders
- ☐ GEC-664, G-E MG Welders
- ☐ GEC-657, Electrode Selector Chart

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City ..... State .....

GENERAL ELECTRIC

NEWS of The Industry

RWMA Announces New Members

The Resistance Welder Manufacturers' Association has announced that Progressive Welder Co. of Detroit, Mich. and United Welders, Inc., of Bay City, Mich., have just become members of that organization.

The Association, under the leadership of J. C. Wilson, Jr., of Acro Welder Mfg. Co., Milwaukee, Wis., who was recently elected RWMA president, is currently expanding its activities and services to members.

The membership of RWMA now includes: Acme Electric Welder Co., Los Angeles, Calif; Acro Welder Mfg. Co., Milwaukee, Wis.; Banner Welder, Inc., Milwaukee, Wis.; Expert Welding Machine Co., Detroit, Mich.; The Federal Machine and Welder Co., Warren, Ohio; National Electric Welding Machines Co., Bay City, Mich.; Precision Welder and Machine Co., Cincinnati, Ohio; Progressive Welder Co., Detroit, Mich.; Resistance Welder Corp., Bay City, Mich.; Swift Electric Welder Co., Detroit, Mich.; The Taylor-Winfield Corp., Warren, Ohio; United Welders, Inc., Bay City, Mich.; Welding Machines Manufacturing Co., Detroit, Mich.

•

Linde Expands Laboratory

Construction is now under way to increase the laboratory facilities of Linde Air Products Co., a Division of Union Carbide and Carbon Corp., on East Park Drive, at Tonawanda, N. Y., according to H. V. Mosby, business manager of Linde's Tonawanda Laboratories. Two new buildings are being constructed to house the expanded research and engineering activities of the laboratories. Construction was started in November 1954, and is expected to be completed in the fall of 1955. General contractor for the work is the Siegfried Construction Co.

Although primarily interested in the production of oxygen, Linde is vitally concerned with all gases in the atmosphere and with their uses in modern industry. From the beginning, Linde laboratories have directed their efforts toward the development of new products and new fields of application.

Originally located on Chandler St. in Buffalo, the Linde Research Laboratories were moved to the present site in Tonawanda in 1938. Expansion has been almost continual, and the last construction was completed in 1953 when an engineering laboratory office was added. The rapidly expanding chemical research and engineering activities are responsible for the present additions designed especially for scientific and engineering research.

•

IAA Elects Bode

J. Carl Bode was recently elected president of International Acetylene Association at its 55th Annual Convention in The Shamrock, Houston, Tex. Mr. Bode is president of National Carbide Co., a Division of Air Reduction Co., Inc.

The new president of IAA was born in Keokuk, Iowa, in 1901. He was graduated from the University of Wisconsin in 1923 with a degree in chemical engineering. Mr. Bode is married and the father of one daughter.

J. Carl Bode

Mr. Bode joined National Carbide in 1928 as superintendent of the Keokuk, Iowa, carbide plant. He was transferred to the new calcium carbide plant in Louisville, Ky., as works manager in 1941. In 1947, he was transferred to the New York offices as operating manager. He was made president of National Carbide in 1948.

The International Acetylene Association, which is one of the oldest technical associations in the country, was organized in 1898 for the purpose of developing broader and more generally useful applications of calcium carbide, acetylene gas and allied products, and to disseminate thoroughly dependable technical information concerning such useful developments. This objective is carried out by the Association through its technical publications, its cooperation with other technical societies, its work with regulatory bodies and its annual convention.

•

Airco Promotes Reed and Donohue

H. H. Reed, district manager of the New York Metropolitan District, was appointed national accounts manager, effective March 1, 1955, it was announced by H. Van Fleet, Jr., regional sales manager in the Atlantic Region, Air Reduction Sales Co. O. M. Donohue, Metro district sales manager, was appointed district manager to succeed Mr. Reed.

Mr. Reed started with Air Reduction in 1923 and held various sales positions in the New York District. He became district manager in 1947, a post he has held until this appointment.

Mr. Donohue, with Airco since 1925, also came up through the ranks in the New York District and has held the position of district sales manager since 1953.

•

P&H "Million Dollar Display"

There were nearly 1000 visitors to the Harnischfeger main factory recently, where they inspected what is believed to be one of the largest inside showings ever held of construction and industrial equipment. This display was in a huge bay in the Milwaukee plant where one million dollars' worth of new equipment including welding equipment, was grouped for inspection. Occasion for the show was the Harnischfeger annual sales conference and open house.

•

Alloy Rods Distributors

E. R. Walsh III, vice-president in charge of sales, announced the appointment of the following new distributors to represent the Alloy Rods Co. in their respective areas: Peerless Supply Co., Inc., 701 Spring St., Shreveport, La., and Sanders and Stewart, Inc., 608 E. Pearl St., Jackson, Mich.

Alloy Rods Co. is located at Lincoln Highway West, York, Pa.

Sprayed Metals Contractors Meet

The METCO System Contractors held their annual meeting in Chicago on Thursday, March 10th. This group specializes in the application of sprayed metal coatings and combinations including sprayed metal and organics. Various combinations of these materials and many technical problems, were discussed. Fred Gartner of the F. W. Gartner Co., Houston, Tex., was elected chairman for the coming year.

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Lincoln Service Pins

The Lincoln Electric Co. recently honored its two oldest employees in point of service at its annual banquet at the Cleveland Hotel. Mary Friedel, a coil winder, and A. F. Davis, vice-president and secretary, each received service pins in recognition of their 40 years of continuous service with the company. A total of 106 of Lincoln's 1100 employees received service recognition. Among the group honored was the largest "class" of 25-year men and women in the company's history. Twenty-six persons received 25-year pins, one of whom was William Irrgang, the company's president.

Leonard Rose and Louis Stevens received 35-year pins. John Kleinhenz, John S. Roscoe and Maurice Taylor received 30-year pins.

•

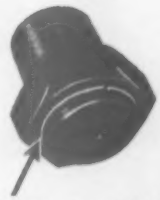
New Coyne Plant

The Coyne Cylinder Co. announces that, in order to better serve the Southwest, Southeast, Midwest and Eastern markets, it has erected a new 14,000-sq ft building at 155 W. Bodley Ave., Memphis, Tenn.

The new building has air-conditioned sales offices, and manufacturing facilities. In addition the plant has a six-car spur track and 18,000 sq ft of yard space.

Coyne feels that this new central location will save its customers thousands of dollars in freight and cut the in-transit time of delivery to most markets by 50%. This facility is in addition to

VISIT THE
WELDING SHOW
MUNICIPAL AUD.
Kansas City, June 8–10

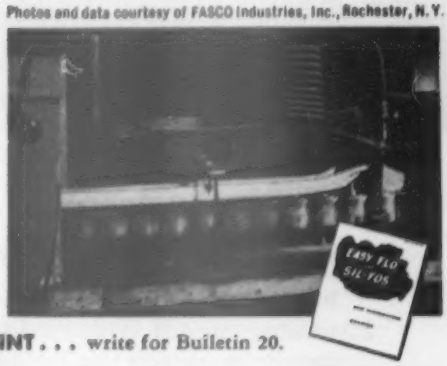


EASY-FLO 45 WIRE RING

HERE'S A TYPICAL EXAMPLE of the reasons why the EASY-FLO low-temperature silver brazing alloys are so extensively used in the automotive and aviation industries. It shows how easy it is to get fast production of high-strength liquid and gas-tight joints with these alloys. And note that no brazing skill is needed. All this adds up to metal joining costs that are surprisingly low.

The unit is a pressure switch which is part of the Studebaker anti-creep "hill holding" device. The job is brazing the threaded spud into the cover. Operator sets covers in cylindrical holders on an endless chain and in the covers she places the spuds, each one with a ring of EASY-FLO45 preplaced. Assemblies pass thru an induction heating coil (below) – 14 a minute.

Photos and data courtesy of FASCO Industries, Inc., Rochester, N.Y.



Expert brazing production know-how at your service

Without obligating you in any way, we'll send a field service engineer to help you work out similar fast, economical production set-ups on your brazing jobs. Just write and say when you would like him to call.

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There's no "...or equal" for EASY-FLO and SIL-FOS

Increase hardfacing production

Constant arc length regardless of operator movement or surface roughness.

HOW THE AMSCO MF WORKS

Bare mild steel electrode continuously feeds through the welding cone. It is magnetically coated with flux of your choice—manganese steel build-up or hardfacing alloy—at the point of the cone. Electrode feed is automatically regulated so that a constant arc length is maintained. Full coil lengths of electrode are consumed, with no loss of stub ends.

automatically...with the

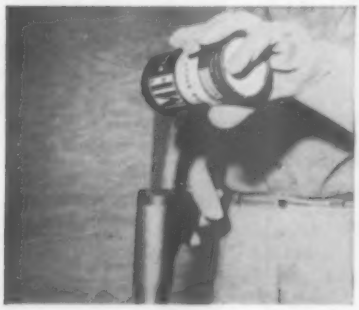
NEW AMSCO® MF WELDER

You steer the cone...the Amsco MF does the work. You lay down more metal in less time, because this welder uses a small diameter electrode and high current densities, which allow a high deposit rate without tiring the operator.

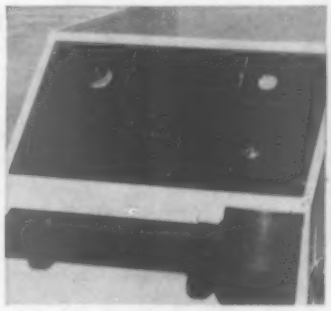
Electrode feed is continuous, and automatically regulated to maintain a constant arc length. This assures a more uniform bead by compensating for operator hand movement and irregular welding surfaces.

Welding is by open arc so you can see what you're doing. The Amsco MF is portable. It plugs into any standard welding unit. It requires no special setup.

See a demonstration of the Amsco MF —its speed, quality of weld and uniform deposit. See how easy it is to operate. Try it and you'll think of many more reasons why it will save hardfacing time and labor costs. Your Amsco Distributor is ready to show it to you now.



Flux held in cone contains the welding alloy you require.



Easily identified, easy to operate panel controls.

Uses small diameter, coiled, bare mild steel electrode.

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Kansas City, June 8-10

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USE THE
TONG TEST
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AMMETER

Machine settings alone cannot control welding quality! Measure actual welding current instantly, accurately and safely by simply clamping a Tong Test Ammeter around the electrode cable. Only Columbia Tong Test measures both AC and DC. Interchangeable ranges available up to 1000 amperes.

Prevent costly defects — increase welding production — maintain valuable equipment—with low cost Tong Test Ammeter. Get the facts today!

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COLUMBIA ELECTRIC MFG. CO.
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the acetylene cylinder manufacturing plant at 200 Paul Ave., San Francisco, Calif.

•

WELDED TANK

This 149-foot-long tank for curing asbestos pipe is one of the longest ever produced at the Bethlehem Steel Co. Made of welded steel plate, it weighs 54 tons and has an outside diameter of over 7 ft.

•

New GE Distributors

Three new distributors have been designated to handle products of General Electric Co.'s Welding Department, according to E. K. How, department sales manager.

The distributors, all of which will handle sales and service of GE's line of arc welders, electrodes and accessories, include: Weld-Arc Sales and Supplies, Inc., 155 E. 44th St., New York City; Interstate Welding Supply Corp., 1067 E. Grand St., Elizabeth, N. J.; and T. H. Green Co., 31 N. Water St., Rochester, N. Y.

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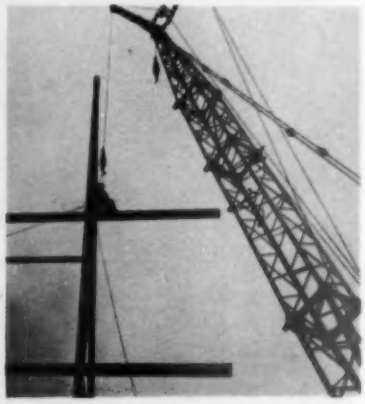
Mrs. McPherson Heads B&M Welding

At the first meeting of the Board of Directors of B&M Welding & Iron Works, Inc., held on February 25th in Gaithersburg, Md., Mrs. Bernice M. McPherson was elected president of the corporation. Maynard McPherson was elected vice-president.

Bernice M. McPherson



Mrs. McPherson "at home" on a construction job

Mrs. McPherson, well known for her practical knowledge of the welding field, started B & M Welding as a one-woman outfit in 1944. Now it has 16 employees and erects almost anything from home-made beams to office buildings, schools, homes, apartments and other structures. Undismayed by height, she can work atop soaring I-beams as handily as on projects where she is underground.

Mrs. McPherson has been extremely active in the affairs of the AMERICAN WELDING SOCIETY for a number of years. At the present time, she is chairman of the Washington Section.

You're entitled to more . . . and you get it!

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ELECTRODE HOLDERS

HERE'S WHY

- Spring completely enclosed and insulated. Cannot be knocked or shorted out.
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Write Today for the complete story of the all NEW HI-AMP Electrode Holder and Ground Clamp.

And that goes for Ground Clamps, too!

- Spring cannot be knocked out
- Spring adjustment screw for easy replacement or adjusting.
- Sturdily built for excessive abuse.
- Designed especially for all-round welder's needs.

Sold only through Welding Supply Distributors throughout the U. S. and Canada.

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Weld with Wagner

PERSONNEL

Boardman Honored with Chairmanship in ASME

Harry Boardman's elevation to chairman of the Boiler and Pressure Vessel Committee of The American Society of Mechanical Engineers comes as a sincere tribute to his professional attainments and his high integrity.

For over 19 years, Mr. Boardman has been a member of the ASME Boiler Code Committee, serving on many of its important subcommittees, frequently as chairman. Prior to his elevation to chairman of the Boiler and Pressure Vessel Committee, his most recent assignments were chairman of the Unfired Pressure Vessel Subcommittee, the Layer Vessel Subcommittee and the Special Committee on Dished Heads. During recent years he has been a member of the Executive Committee, and chairman of the ASME representatives on the Joint API-ASME Committee on Unfired Pressure Vessels. He also has been on the Subcommittees on Openings and Bolted Connections, and Special Design, and on Welding.

Mr. Boardman's many years as a professional man have not been limited to ASME work. He has been active in the Welding Research Council, and at one time was chairman of the Council and is a member of the Executive Committee. He is now chairman of both manufacturers' subcommittees on storage tanks for the API.

He was president of the AMERICAN WELDING SOCIETY and served on various subcommittees. He has a great talent for assembling information and has given considerable time and help in the preparation of codes. He was a member of two WELDING HANDBOOK Committees, and was chairman of the committee which published the Third Edition in 1950.

Many other honors have been bestowed on him including the AWS Miller Award in 1942. This year he has been designated as an alternate delegate for the International Institute of Welding.

Mr. Boardman started with Chicago Bridge & Iron Co. in the main office at Chicago in 1910, serving as a draftsman and chief draftsman. He went to Texas with the National Guard in 1916, returned and later entered World War I. He rejoined C. B. & I. as a research engineer in 1926, after serving several years on the faculty of the University of Illinois. Since 1945, Mr. Boardman has been director of research.

Jack J. Jarms

Jarms Appointed

The new job of welding positioner specialist for the Harnischfeger Corp., Milwaukee, has recently been filled by Jack J. Jarms, according to an announcement by W. R. Stephens, sales manager of the Welding Division. In his new capacity, Mr. Jarms will coordinate P&H Welding Positioner Sales, and sales policy between the Home Office and Welding Division District Managers and Salesmen, as well as between Distributors and their salesmen. He will also administer the P&H Positioner Educational Program.

Kinzel Receives 1954 Morehead Medal

The 1954 James Turner Morehead Medal of the International Acetylene Association has been awarded to Dr. Augustus B. Kinzel, director of research, Union Carbide and Carbon Corp. Dr. Kinzel received the medal for his scientific and technological contributions to acetylene utilization. The medal was presented to Dr. Kinzel during the Convention of the International Acetylene Association at The Shamrock in Houston, March 22–24.

The Morehead Medal is awarded annually by the Association to the person or persons who in the judgment of its officers and board of directors, has done most to advance the industry or the art of producing or utilizing calcium carbide or its derivatives, the most important of which is the gas, acetylene.

Dr. Kinzel joined Union Carbide as a research metallurgist in 1926. His research contributions to the work of Union Carbide have covered a wide range of activities in the fields of industrial gases, metallurgy and atomic energy. He pioneered in the theory of stainless steels, the development of weldable alloy structural steels and the research and development of special alloying metals. Union Carbide's new process for titanium crystals is largely creditable to Dr. Kinzel's research leadership. More than 40 United States patents have been issued to him.

Dr. Kinzel is a member of the AMERICAN WELDING SOCIETY and is the author of scores of technical and scientific articles on welding, applied mechanics, engineering, testing and metallurgy.

Mathy Promoted

Ernest L. Mathy, for over 30 years intimately connected with the welding industry, has been elected a member of the board of directors of National Welding Equipment Co. of San Francisco,

Ernest L. Mathy

Calif., and Hugh F. Brown, president, announces Mr. Mathy's appointment to the position of vice-president and general manager of the company.

Willey Joins ASF

Robert A. Willey joined the staff of the Steel Founders' Society of America on March 1st as assistant technical and research director. Mr. Willey comes to the Society directly from The Commercial Steel Casting Co., Marion, Ohio, where he was chief metallurgist.

Mr. Willey has been a member of the SFSA Technical Research Committee since 1950. He is also a director of the Acid Open Hearth Research Association, and has served a two-year term as a member of the Papers and Program

CHAMPION PIONEERS AGAIN —

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NEW ELECTRODES

for Welding

CHROME-MOLY

ALLOY STEELS

Champion now brings to the fabricator of Chrome-Moly Steels a new type of low hydrogen electrode of the AWS xx15 type, excellent for all position welding.

Champion's Croloy Electrodes produce a weld deposit with a carefully controlled composition which almost completely eliminates weld cracking and greatly reduces the preheat necessary as well as relieving the necessity of maintenance of preheat prior to stress relieving.

Champion Croloy Electrodes produce very smooth weld deposits in all positions and pass the most rigid X-ray requirements. Weld deposits from Croloy Electrodes possess very high ductility, 20-26% in the as-welded condition, and 24-30% stress relieved at 1350°F, as well as show stress-to-rupture properties equal to or exceeding that of the plate material. Champion Croloy Electrodes 3/32" through 3/16" diameters are available in grades for welding .5% Cr, .5% Mo through 5% Cr, .5% Mo material.

Complete technical data on Champion Croloy Electrodes will be furnished upon your letterhead request. Write Now! Dept. W

THE CHAMPION RIVET COMPANY

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Robert A. Willey

Committee of the American Foundrymen's Society. His other memberships include the American Society for Metals, the American Institute of Mining & Metallurgical Engineers, the Society for Non-Destructive Testing and the AMERICAN WELDING SOCIETY.

He is the author of several papers which have appeared in *Steel Foundry Facts, Proceedings* of the AIME Electric Furnace Conference, Foundry, *Non-Destructive Testing Magazine, Industry & Welding, The American Foundryman* and a chapter of the A.F.S. Sand Handbook.

His experience encompasses the field of chemical analysis, sand, composition control, radiography, heat treating, welding materials and techniques, specifications, gating and open-hearth melting of steel.

Mr. Willey is a graduate of Ohio Wesleyan and also of Ohio State University. Prior to 1942, he was for eight years a teacher of mathematics, physics and chemistry.

Jones Appointed

Wm. Loveman, president, The Burdett Oxygen Co. of Cleveland, Ohio, announces the appointment of Wendell Jones as plant manager of the Burdett Youngstown, Ohio, branch.

Mr. Jones has been with both the

Wendell Jones

Cleveland plant and the Youngstown branch for several years. He is a member of the AMERICAN WELDING SOCIETY.

OBITUARY

Finn Jonassen

Dr. Finn Jonassen's death on Feb. 19, 1955, in Washington, D. C., ended a valiant fight for life; after repeated interruptions caused by ill health over the past several years, his services to engineering research are ended.

For the past nine years, Dr. Jonassen served as technical director of the several National Academy of Sciences - National Research Council committees advisory to the Ship Structure Committee. He was the moving genius of the long series of postwar experimental studies which grew out of the wartime service fractures of merchant vessels.

Dr. Jonassen was born in Norway of a seafaring family in 1907 and came with his family to America in 1919. From Brooklyn schools he went to drafting jobs, first in 1924 with the Sperry Gyroscope Co., and then in 1925 with Steel and Condict, Inc., in Jersey City. Two years of technical study at Pratt Institute between 1927 and 1929 prepared him for responsibility in the design and construction of heavy machinery with the McKiernan-Terry Corp.

In 1934 he married Lucie Andrea Andresen. In that same year, he entered the University of California at Berkeley as an undergraduate in mechanical engineering. After graduation in 1937, he continued with advanced study and instruction. He was awarded the degree of Doctor of Philosophy in 1941.

In 1942 Dr. Jonassen supervised war training courses of engineering instruction sponsored by the University in Los Angeles and San Diego, and in 1943 was drawn into wartime welding research projects. These projects, sponsored at first by the Office of Scientific Research and Development and the War Metallurgy Committee of the Academy-Research Council, became of considerable significance in the winter of 1942–43 and even more so during the winter of 1943–44 when merchant vessels in increasing numbers were damaged and some of them lost as a result of unexplained brittle fractures of the hull plating. Early in 1944, the Secretary of the Navy formed an inter-agency "Board of Investigation to Inquire into the Design and Methods of Construction of Welded Steel Merchant Vessels." The Board worked in cooperation with the OSRD from the beginning and Dr. Jonassen had a prominent part in its West Coast activities.

At the end of hostilities it became apparent that research on brittle fracture would have to be carried further. The OSRD was being discontinued and in the process of readjustment, the Board was reorganized under the Secretary of the Treasury as the inter-agency Ship Structure Committee. The Ship Structure Committee then requested the National Academy of Sciences - National Research Council to provide advisory guidance on the then active research projects and in formulating a continuing research program. The choice fell on Dr. Jonassen, who then resigned his position as associate professor of mechanical engineering at Berkeley and moved to Washington permanently.

In his vigorous pursuit of the objectives of the research programs, Dr. Jonassen traveled widely and made fruitful contact with men in metallurgy and structural engineering research in all parts of the United States and abroad.

In temperament he was gentle though persistent. He neither threatened nor cajoled, but the work which he directed was molded by a kindly but pervasive pressure. He was scrupulous, kind, modest.

The number of papers which he authored or co-authored is modest yet their contributions are significant; his name might appropriately be appended as joint author on nearly every one of the almost 100 Ship Structure Committee reports.

Gertrude Hungerford Mackenzie

On March 11th, welding lost a loyal friend and staunch supporter when death came to Mrs. Gertrude H. Mackenzie, whose husband founded *Welding Engineer* in 1916. Mrs. Mackenzie became publisher of the magazine in 1924 and carried on until the magazine was sold to the McGraw-Hill Publishing Co. in 1945.

On Oct. 11, 1945, on the occasion of the 25th anniversary dinner of the Chicago Section, the Section presented Mrs. Mackenzie with a silver picture, in honor of the role she and her husband had played in founding the Section. Louis B. Mackenzie played an important part in the organization of the AMERICAN WELDING SOCIETY and was one of the driving powers behind the Chicago Section.

Although retired from active business, Mrs. Mackenzie never lost interest in the welding industry. Modest, and having no desire for personal acclaim, she did much to promote the cause of welding.

ARCAIR torch cuts assembly time 20% in fabricating steel tanks

A NEW TIME and money saving procedure for tank fabrication has been developed in the Seattle, Washington, shops of the Olympic Welding Co., based on the use of the Arcair torch.

In this procedure steel plates are set up for welding, square-butted against one another. A light sealing pass is made on the *inside* of the seam, enough to hold the plates in correct alignment, and the outside seam is left *untouched*. The welder then makes one pass with the Arcair torch, to gouge out the outside seam, which leaves an even, clean groove ready for welding, which was then filled with two passes to give a 100% weld.

The shop foreman at Olympic reports that this new fabrication method has been saving up to 20% in assembly time by eliminating beveling of plates before fit-up and preparing both sides of the groove simultaneously. Transverse sections and tensile tests showed penetration superior to conventional beveling and welding techniques.

Other methods of gouging, including special gouging electrodes, had previously been tried on this job but with little success, because of uneven grooves produced and prohibitive costs of special gouging electrodes. Chipping or grinding also proved impractical on this application. Olympic also uses their Arcair torches to repair defects.

Olympic Welding is one of a great variety of industries throughout the world, that have found that use of the Arcair torch solves their metal removing problems faster and cheaper, besides giving a better finished job. Ask your welding supply dealer for a free demonstration in your plant.

Write TODAY for free bulletin showing facts and figures of time and money-saving Arcair applications using the Arcair torch.

ARCAIR COMPANY
431 South
Mt. Pleasant Ave.
Lancaster, Ohio

Arcair TORCH

EMPLOYMENT SERVICE BULLETIN

Services Available

A-666. Sales Engineer. Age 38. Married. Veteran. Six years' practical experience in welding and fabricating. Two years' experience in sales and service with flame-cutting equipment, oxy-acetylene and arc welding, inert arc welding and inert arc spot welding equipment. Capable of recommending proper procedures and techniques with above equipment. Desire similar position in sales engineering. Will relocate. Prefer middle west.

A-667. Welding Engineer Supervisor. Fifteen years' experience. Fully responsible for all metal joining process development, standardization, instruction on tubes, lamps, hi-temp metals for major multi-plant electrical manufacturer. Proved record; many National Society papers. M.S. degree, top references. Age 35. Relocation sought with new challenges, incentives, management advancement opportunities.

A-668. Welding and Fabricating Foreman, Technician. Fourteen years' experience, including supervisor in welding and fabricating shop. Full knowledge of manual arc welding, manual and machine flame cutting, automatic submerged arc welding, manual semiautomatic submerged arc welding, inert gas arc welding. Background in experimental work, instruction and testing of welders. Age 37. Married. Résumé and references upon request.

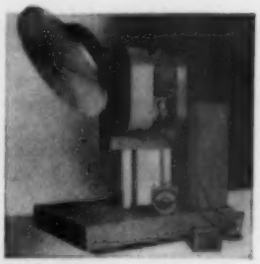
Position Vacant

V-320. Welding Engineer to head welding research section of a leading manufacturer of alloy, stainless, tool steels and high-temperature alloys. A solid background of experience with various welding methods and techniques as applied to alloys difficult to weld is essential. Location, Pittsburgh. In reply, submit full résumé, personal description and indicate salary requirement.

Steady, Positive, Precision Rotation for AUTOMATIC WELDING with *Aronson* Positioning Equipment.

UNIVERSAL Balanced POSITIONING
Model C 500 shown
25 lbs. to 2,000 lbs. capacity

HEAVY DUTY GEAR DRIVEN POSITIONING
Model HD 25 shown
500 lbs. to 24,000 lbs. capacity



HEAD and TAIL STOCK POSITIONING
Model HTS 5 shown
Capacities 5,000 lbs. to 160,000 lbs.

MODEL 21 (shown) SUPER GEAR DRIVEN POSITIONER with powered rotation tilt and elevation.

MODEL X-21 Powered rotation, ball bearing manual tilt and elevation.

MODEL 21-P Powered rotation and tilt, ball bearing manual elevation.

MODEL 21-E Powered rotation and elevation, ball bearing manual tilt.

MODEL X-21-PE Powered rotation, tilt and elevation. 5000 lbs. capacity @ 6" CG location.

Aronson TRACTRED Turning Rolls
Steady, positive, precision rotation for automatic welding. MODEL T1 (shown) capacity 6,000 lbs. per unit. MODEL T2 capacity 12,000 lbs. per unit. MODEL T3 capacity 18,000 lbs. per unit.

HEAVY-DUTY PRECISION BUILT RUBBER TIRED TURNING ROLLS
5,000 lbs. to 150 tons capacity

Aronson MACHINE COMPANY
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HELP WANTED

Design Engineer. Leading Manufacturer of Automatic Welding Machinery desires aggressive man with experience in design of Welding Automation equipment. Background should be both electrical and mechanical, preferably with some knowledge of welding application. Unlimited opportunity with fast growing company. Send résumé, state qualifications and salary expected. All replies held in strict confidence.

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WELDING RESEARCH

Opening for young engineer interested in rapid professional growth in the metallurgy of welding. Expanding program requires high quality metallurgical training and interest in pursuing programs covering broad fields related to welding. Liberal benefits including tuition free graduate study. Write:

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Chicago 16, Illinois

T.I.G. and M.I.G. WELDING GAS COSTS CUT UP TO 81%

WITH NEW LIQUID CARBONIC CO_2 METHOD

For Carbon and Stainless Steels

Low Cost CO_2 Gas provides 75% of protective atmosphere. Consumption of expensive argon or helium is cut to ¼ of present use.

High Quality, High Speed Welds. LIQUID'S new CO_2 dual method changes nothing but the high cost!

Use Your Present Equipment— hand or automatic. Simply attach one of LIQUID'S low cost adapter kits and start saving *now!*

No New Technique To Learn. Welding procedure is the same as for conventional shielded gas welding.

For Highest Performance Specify

RED DIAMOND WELDING CO_2

Specifically developed for shielded gas welding. Brought to you in specially marked cylinders. LIQUID also produces Oxygen, Acetylene and other commercial gases for industrial use.

LIQUID Dual Gas Welding Kits

Kit for hand torches (pictured) consists of CO_2 regulator, calibrated flow meter, plastic hose and dual gas nozzle assembly. Dual gas welding adapter kits are also available for M. I. G. equipment. Write for prices and complete information.

Liquid

COMPRESSED GAS DIVISION

THE LIQUID CARBONIC CORPORATION
3144 South Kedzie Ave., Chicago 23, Ill.

FOR A DEMONSTRATION
Visit us at Booth 125

WELDING SHOW

MUNICIPAL AUDITORIUM, Kansas City
June 8—10

ALSO ON DISPLAY: our complete line of GASWELD Gas Welding and Cutting Equipment, also LIQUID Arc Welding Machines

NEW PRODUCTS

Welder's Glove

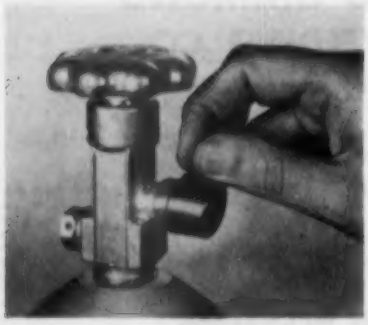
The Singer Glove Manufacturing Co. of Chicago is now producing a new glove with several features which reportedly make it highly suitable for its purpose.

Described by the manufacturer as a

premium quality welder's glove, made of specially tanned leather, this glove offers extended welted seams on all fingertips for longer life and greater ease in picking up materials. For further details write to manufacturer.

Plastic Caps

An inexpensive flexible plastic cap designed to offer improved protection for gas cylinder valve outlets during shipping, handling and storage has been announced by the S. S. White Plastics Division.



The caps supposedly assure positive protection against thread damage and keep dirt and moisture out of the outlet. They are available in two sizes for 0.825 in. OD and 0.903 in. OD threaded outlets.

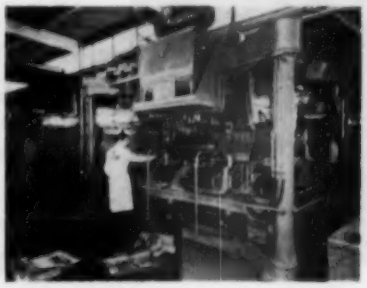
Full details available from the S. S. White Plastics Division, 10 E. 40th St., New York 16, N. Y.

Nicol-Rod

A new welding electrode with a Ferromolostic (special powdered iron) coating is announced by the Marquette Manufacturing Co. Inc., 307 E. Hennepin Ave., Dept. NS, Minneapolis, Minn. Known as Nicol-Rod No. 99, it is claimed to alloy pure nickel with iron to produce dense, high-strength, machineable welds in gray, malleable and ductile cast irons.

Link Welding Press

The Link Welder Corp., Detroit, announces that it has developed a type of resistance welding press so versatile that it is adaptable not only to the automotive field, but also to a broad variety of sheet metal fabrication and end product manufacture in almost every industry; aircraft, furniture, chemical processing, utensil and plumbing fixture fields.



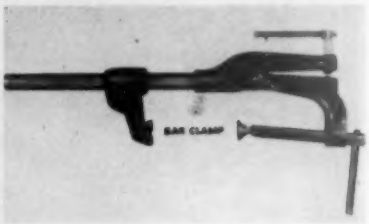
Link Welder engineers report that this resistance welding machine lends itself to a variety of complete tooling changes to meet specific metal fabricating requirements. The four-post mechanical welding press will accept any welding fixture necessary to perform the fabrication.

The first series of these Link welding machines are now fabricating complete floor panel assemblies for one of the nation's major automobile manufactures. Actually, one of these machines welds floor panels for convertible, two-door, four-door and station wagon models produced by this auto maker.

Further details on Link Welder multiple-point, resistance-welding machines can be obtained by writing to Link Welder Corp., 13684 W. Buena Vista, Detroit 27, Mich.

Bar Clamp

Grand Specialties Co. announces the availability of its new Quickcet Bar Clamp which is claimed to be particularly useful to welders and machine tool shops. It is designed to firmly hold small or large objects formerly too bulky to handle. This heavy-duty, $^3/_4$-in. pipe bar clamp with sliding jaw for quick adjustments can be used either

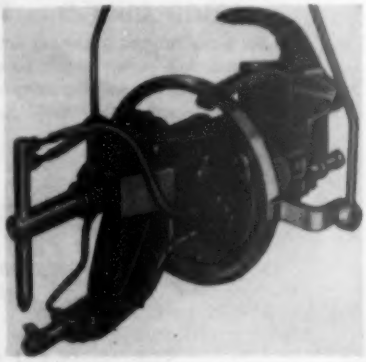


vertically or horizontally. Made of alloy steel, it has been proof tested to 4500 lb. The Grand Quickcet Bar Clamp weighs 8 lb and has a 15-in. opening capacity with its standard 12-in. pipe bar; however extra bar extensions of any length can be furnished.

For complete details and information write to Grand Specialties Co., Dept. PC, 3101 W. Grand Ave., Chicago 22, Ill.

Portable Spot Welder

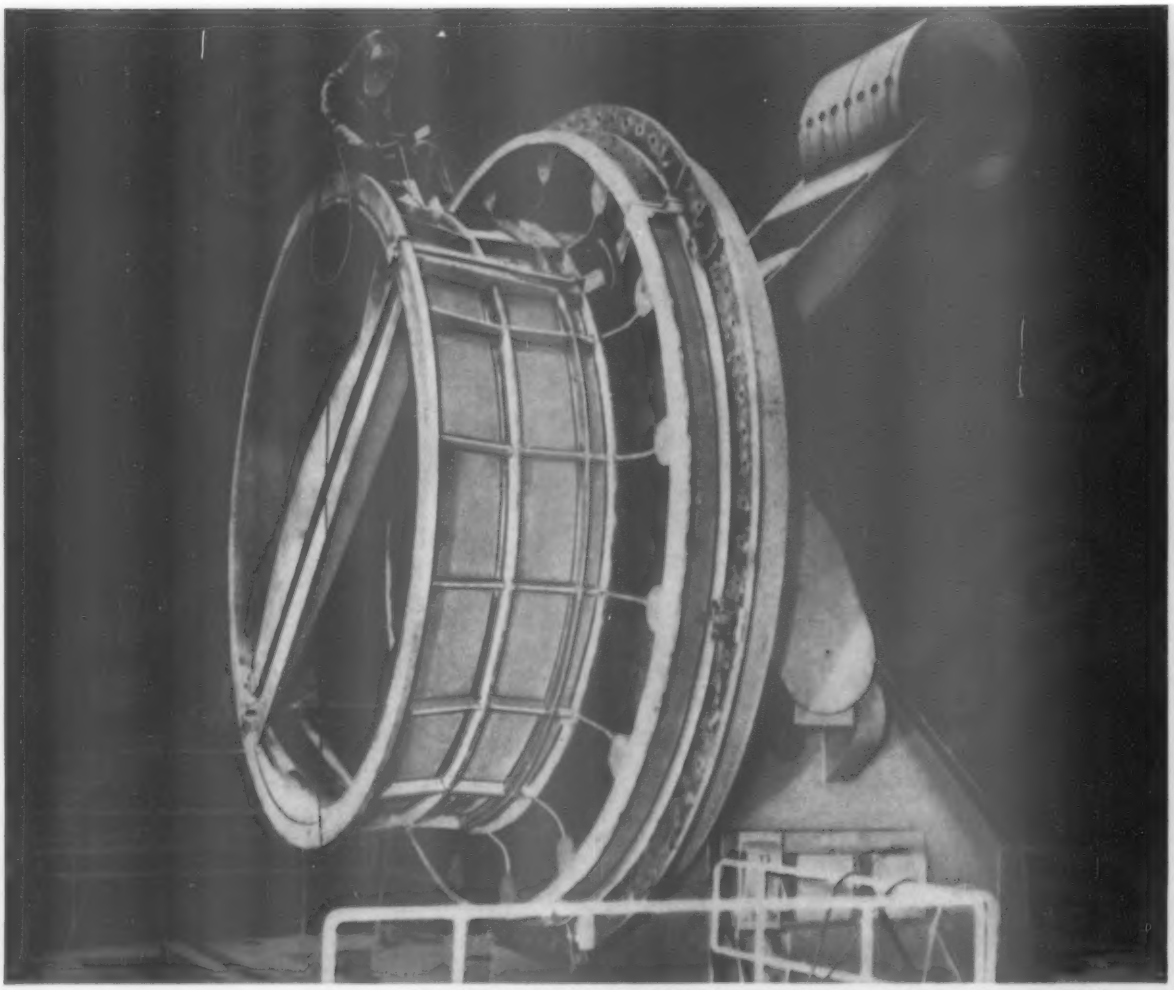
A new type of portable spot-welding equipment is being introduced by the ARO Spotwelders Corp., 87 Hamilton Pl., New York 31, N. Y.



A full line of welders with transformer and arms incorporated into one unit ranging in capacity from 18 to 12 gage is available. All models feature high, adjustable spring pressure, foolproof tripswitch or automatic timer.

for SOUND WELDS

An air-hydraulic unit with pistol-grip trigger is the last word in automation and is designed for heaviest production on sheet steel up to 2 x 12 gage.



DOWNHAND WELDING of huge weldments at the S. Morgan Smith Co. is made easy by automatic Worthington welding positioner.

World's largest welding positioner

Handling 64,000-lb weldments was the problem facing engineers in the S. Morgan Smith Company plant in York, Pa.

Correct positioning of pieces this big would be exceptionally expensive if ordinary methods were used.

So this leading turbine manufacturer turned to Worthington for help — and got the world's largest welding positioner.

The extra capacity of this Worthington Model 600 Positioner (it's designed for loads up to 50 tons) is matched by many other Worthington "extras". Worthington's top-notch field service and creative engineering background are more reasons why the *important* positioning jobs — large and small — go to Worthington.

Write for Bulletin R1700S11 today. Worthington Corporation, Positioning Equipment Division, Harrison, N.J. Y.S.1

WORTHINGTON

Drop in and see us at the Welding Show, Kansas City Mo. June 8–10 Booths 236–238

Welding Positioners • Turning Rolls

The new Mid-States combination welder is complete with gas controls, self-timer, heavy-duty magnetic contractor, remote control circuit, and can

From any angle...

YOUR BEST ELECTRODE

for SOUND WELDS

with OUTSTANDING PHYSICALS

use NEW Bronze-Arc C

PHOSPHOR BRONZE ELECTRODES

Another "first of its kind" development of Alloy Rods Company research brings an entirely new phosphor bronze electrode—Bronze-Arc C. Incorporating a unique low hydrogen type coating, Bronze-Arc C electrodes have demonstrated advantages . . . porosity-free deposits, all-position welding, smooth easy flowing arc characteristics, easy slag removal and outstanding physical properties.

Typical Physical Properties of Bronze-Arc C Electrodes

Tensile Strength p.s.i.	58,000 to 65,000
Yield Strength p.s.i.	30,000 to 37,000
% Elongation in 2" ga.	42% to 48%
Hardness, Rockwell B	72 to 78
Face Bend	180°
Root Bend	180°

Bronze-Arc C conforms to A.W.S.—A.S.T.M. Specification No. B-225-53T, Classification E CuSn-C.

Write today for complete information on new Bronze-Arc C electrodes—the electrodes designed especially for high strength, X-Ray quality welds.

VISIT OUR BOOTH 227
at WELDING SHOW
MUNICIPAL AUDITORIUM
Kansas City, June 8-10, '55

Alloy Rods Co.

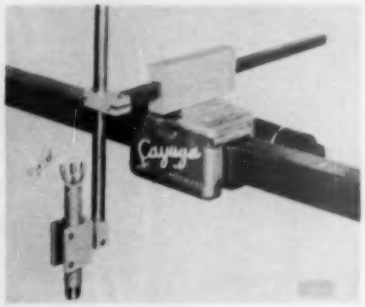
General Offices and Plant • York 3, Pa.
Pacific Coast Sales Office and Plant
El Segundo, Calif.

no finer electrodes made . . . anywhere

An air-hydraulic unit with pistol-grip trigger is the last word in automation and is designed for heaviest production on sheet steel up to 2 x 12 gage. Also offered for the first time is a portable Twin-Spot-Gun for series welding without backup electrode.

Portable Welder

A new portable seam welder, for welding seams from 5 to 20 ft long, has just been announced by the Cayuga Machine and Fabricating Co., Inc., Depew, Buffalo, N. Y. It is a self-contained



unit with its own rail supported by either tripods or magnetic clamps. For further details write directly to the company.

Spot Arc Welder

A new spot arc welding unit recently developed by Mid-States Welder Manufacturing Co., Chicago, is now available. It is claimed to be ideally suited to sheet welding applications where it is possible to work from one side of the sheet only.

The Spot Arc process is basically the same as the inert-arc welding process in that the welding arc is formed between the tungsten electrode and the workpiece shielded by an inert gas atmosphere. The only difference is that the length of time the arc is on is timed accurately so that merely a puddle of molten metal is formed.

Q. What controls the quality of consumable electrode welding?

The new Mid-States combination welder is complete with gas controls, self-timer, heavy-duty magnetic contractor, remote control circuit, and can be attached to any a-c welding power source of approximately 300 amp capacity.

For additional information write directly to the company.

Croloy Electrodes

A new system of arc welding which supposedly reduces to a minimum the need for preheating and heat treatment subsequent to welding is announced by Metal & Thermit Corp., New York. Specifically intended for welding chromium-moly steels used in equipment for high-pressure high-temperature services. This new concept of welding employs a group of chromium-moly electrodes, called Croloy. Weld deposits of Croloy electrodes are claimed to exhibit unusual stress-rupture characteristics over a wide range of temperatures, along with outstanding ductilities and resistance to corrosion and oxidation.

Detailed information on Murex Croloy electrodes and the new fabricating procedures they make possible may be obtained by writing Metal & Thermit Corp., 100 E. 42nd St., New York 17, N. Y.

"Aircraft Special" Welder

A new electric motor driven d-c are welder with an extremely wide welding range of 5- to 300-amp is being announced by Hobart Brothers Co., Troy, Ohio.

It has a normal rating of 200 amps for average welding work and, according to the manufacturer, it has the added ability to get down to exceptionally low heats for best results in welding very light gage metals such as used in aircraft welding, body and fender work.

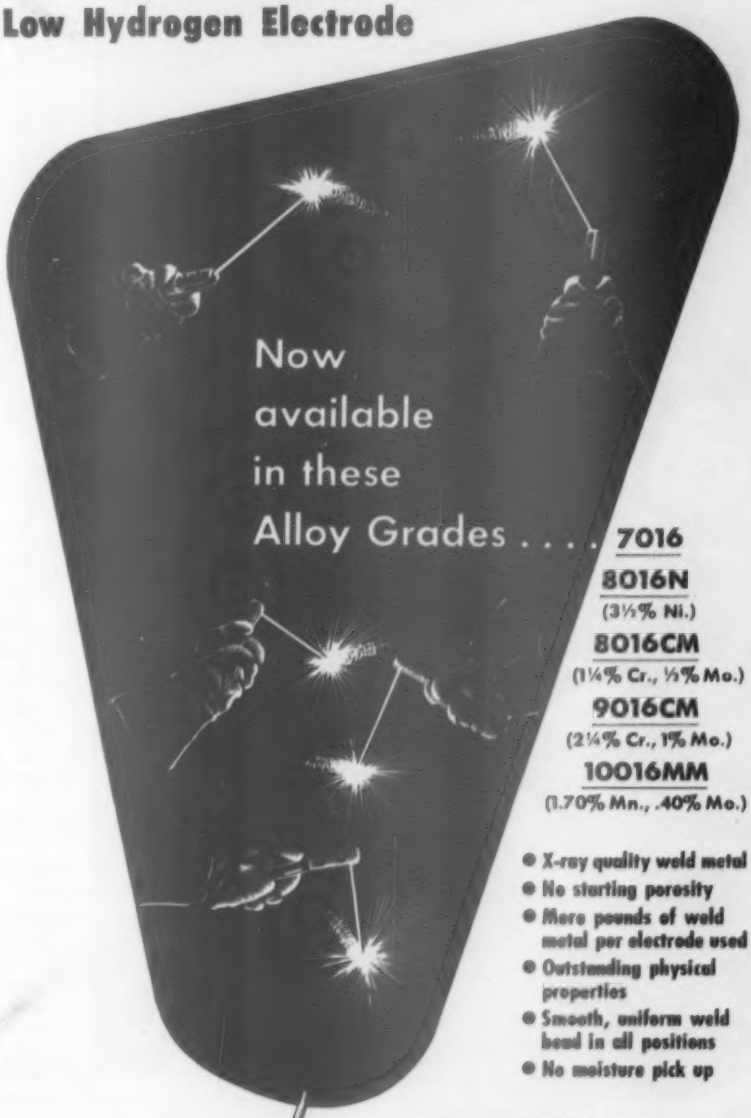
For complete information, write Hobart Brothers Co., Troy, Ohio.

From any angle...

YOUR BEST ELECTRODE

ATOM-ARC

The ONLY All-Position Iron Powder Low Hydrogen Electrode



7016
8016N
(3½% Ni.)
8016CM
(1¼% Cr., ½% Mo.)
9016CM
(2¼% Cr., 1% Mo.)
10016MM
(1.70% Mn., .40% Mo.)

- X-ray quality weld metal
- No starting porosity
- More pounds of weld metal per electrode used
- Outstanding physical properties
- Smooth, uniform weld bead in all positions
- No moisture pick up

VISIT OUR BOOTH 227
at WELDING SHOW
MUNICIPAL AUDITORIUM
Kansas City, June 8-10, '55

Alloy Rods Co.

Get the complete story now...
Write today for your copy of the ATOM • ARC Bulletin — it tells you what you want to know about this revolutionary new electrode.

General Offices and Plant • York 3, Penna.
Pacific Coast Sales Offices and Plant
El Segundo, Calif.

no finer electrodes made ... anywhere

Q. Where is Alcoa's new I.G. Electrode available?

Sound Barrier Curtain

Bemis Brothers Bag Co. reports the

Q: What controls the quality of consumable electrode welding?

A: One big factor is the quality of the electrode used.

Q: How can you be sure of getting the best electrode?

A: By insisting on Alcoa's new I.G.* Electrode.

Q: Why?

A: Every production lot of Alcoa® I.G. Electrode is test welded and the welds X-rayed for soundness. Each 10-lb spool is individually packed to maintain the super-smooth finish to assure soundness of weld and smoothness of feed. Each of five alloys, 1100, 4043, 5154, 5254 and 5356 (formerly 2S, 43S, A54S, B54S and XC56S), is available in six diameters. There is no better electrode.

*inert gas

Your guide to aluminum value

I.G. ELECTRODE MADE OF
ALCOA ALUMINUM
ALUMINUM COMPANY OF AMERICA

A new, 176-page text, *Welding Alcoa Aluminum*, has just been released by Alcoa. It covers every phase of welding in complete detail. For a free copy, fill in and mail the coupon.

ALUMINUM COMPANY OF AMERICA
1741-E Alcoa Bldg., Mellon Square
Pittsburgh 19, Pa.

Gentlemen: Please send book, *Welding Alcoa Aluminum*,

Name_____

Company_____

Title_____

Address_____ City_____ State_____

Q. Where is Alcoa's new I.G. Electrode available?

A. Contact your nearest Alcoa sales office, or, for immediate delivery, call one of the Alcoa Distributors listed below. He carries a complete range of alloys and sizes, and you'll find him well qualified to work with your welding experts.

ALBANY, N. Y.
†Eastern Brace-Mueller-Huntley, Inc.

ATLANTA, GA.
†J. M. Tull Metal & Supply Co., Inc.

BALTIMORE, MD.
Whitehead Metal Products Co., Inc.

BIRMINGHAM, ALA.
†Hinkle Supply Co.

BOISE, IDAHO
Pacific Metal Co.

BUFFALO, N. Y.
Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.

CAMBRIDGE, MASS.
Whitehead Metal Products Co., Inc.

CHARLOTTE, N. C.
Edgcomb Steel Co.

CHICAGO, ILL.
†Central Steel & Wire Company
†Steel Sales Corporation
Corey Steel Co.

CINCINNATI, OHIO
Williams & Co., Inc.

CLEVELAND, OHIO
†The Hamilton Steel Co.
Williams & Co., Inc.

COLUMBUS, OHIO
Williams & Co., Inc.

DALLAS, TEXAS
Metal Goods Corp.

DENVER, COLO.
Marsh Steel Corp.
Metal Goods Corp.

DETROIT, MICH.
Central Steel & Wire Co.
Steel Sales Co. of Mich.

HARRISON, N. J.
Whitehead Metal Products Co., Inc.

HILLSIDE, N. J.
Miller Steel Co.

HOUSTON, TEXAS
Metal Goods Corp.

INDIANAPOLIS, IND.
Steel Sales Co. of Indiana, Inc.

JACKSONVILLE, FLA.
Florida Metals, Inc.

KANSAS CITY, NORTH, MO.
†Marsh Steel Corp.
Metal Goods Corp.

KENILWORTH, N. J.
Kenilworth Steel Co.

LOS ANGELES, CALIF.
†Ducommun Metals & Supply Co.
Pacific Metals Co., Ltd.

LOUISVILLE, KY.
Williams & Co., Inc.

MIAMI, FLA.
Florida Metals, Inc.

MILFORD, CONN.
†Edgcomb Steel of New England, Inc.

MILWAUKEE, WIS.
Central Steel & Wire Co.
Steel Sales Co. of Wis.

MINNEAPOLIS, MINN.
Steel Sales Co. of Minnesota

NASHUA, N. H.
Edgcomb Steel of New England, Inc.

NEW ORLEANS, LA.
Metal Goods Corp.

NEW YORK, N. Y.
Adam Metal Supply Co., Inc.
Eastern Brass & Copper Co.
Manhattan Brass & Copper Co.
Straus Aluminum Co.
†Whitehead Metal Products Co., Inc.

PHILADELPHIA, PA.
†Edgcomb Steel Co.
Whitehead Metal Products Co., Inc.

PITTSBURGH, PA.
†Williams & Co., Inc.

PORTLAND, ORE.
†Pacific Metal Co.

ROCHESTER, N. Y.
Brace-Mueller-Huntley, Inc.

ST. LOUIS, MO.
†Metal Goods Corp.

SALT LAKE CITY, UTAH
Pacific Metals Co., Ltd.

SAN DIEGO, CALIF.
Ducommun Metals & Supply Co.
Pacific Metals Co., Ltd.

SAN FRANCISCO, CALIF.
†Pacific Metals Co., Ltd.

SEATTLE, WASH.
Pacific Metal Co.

SYRACUSE, N. Y.
†Brace-Mueller-Huntley, Inc.
Whitehead Metal Products Co., Inc.

TAMPA, FLA.
†Florida Metals, Inc.

TOLEDO, OHIO
Williams & Co., Inc.

TULSA, OKLA.
Metal Goods Corp.

YORK, PA.
Edgcomb Steel Co.

†Home Office

Sound Barrier Curtain

Bemis Brothers Bag Co. reports the development and production of TransWall, a lightweight, retractable sound barrier curtain designed especially for industrial applications.

Actually a high density folding curtain, TransWall serves as a sound-reduction wall that can be quickly installed at low initial cost and used to subdivide an area into any number of independent units.

For more information write to Bemis Brothers Co., 325 27th Ave., N. E., Minneapolis, Minn.

"Tigerbraze"

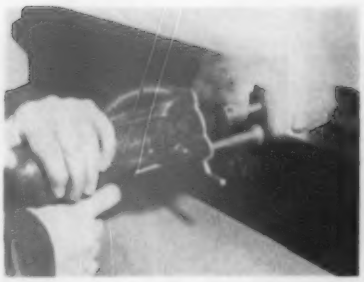
A new method which literally "flashes" signal bonds onto railroad rails is claimed to be one of the biggest improvements made in railbonding in the last 30 years.

The new bond, known as "Tigerbraze," is the result of three years of cooperation and research between U. S. Steel's American Steel and Wire Division, Nelson Stud Welding of Lorain, Ohio, and AGA (Svenska Ab Gasaccumulator) of Stockholm, Sweden.

Tigerbraze permits the 5-in. flexible bronze cable rail bond to be brazed to the side of a rail end in a few seconds. The special gun developed by Nelson Stud Welding delivers a controlled electric arc which generates sufficient heat to form the braze in one second. AGA's experience suggested the use of silver solder which lends itself to low-temperature brazing, resulting in a tight and permanent bond.

When the gun trigger is depressed, causing the braze current (200 amp at 36 v) to be struck, it flashes off the tip of the silver solder portion allowing the flux to cleanse the braze area.

The duration and temperature of the arc are only enough to melt the silver solder. When the brazing current ceases, the steel pin is automatically plunged into the molten pool of silver



solder by the gun pushing the solder underneath the copper lug.

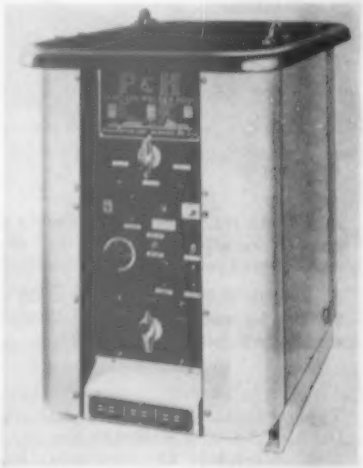
Equipment for fastening the rail bonds includes a Nelson gun, batteries and a small gasoline-driven battery charger compactly mounted on the cart.

Equipment for the Tigerbraze bonding operation is mounted on a lightweight cart which rides on the rails or on retractable rubber tire wheels. A single workman can trundle the cart on or off the track in half a minute.

The Tigerbraze bonds and the installation cart and equipment will be merchandised to the railroads through American Steel and Wire Division.

Arc Welders

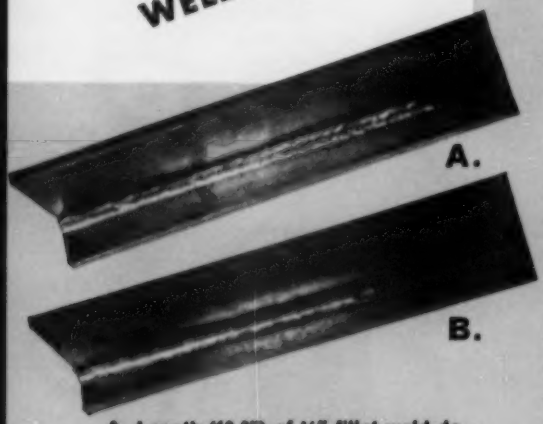
Two new welders have been announced by the Harnischfeger Corp. W. R. Stephens, sales manager of the Welding Division, says that the units are actually seven welding machines in one, and that they provide the operator with either ac or dc welding current at the flip of a switch.



Two models, designated the DA-200HF-GW (200 amp) and DA-300HF-GW (300 amp) are available, and according to the manufacturer are each adaptable to seven different welding processes. Harnischfeger claims they can be used for metallic arc welding, ac or dc, either straight or reverse. With the proper torch, they can be used for

NEW NCG® SUREWELD®
IRON POWDER
ELECTRODES

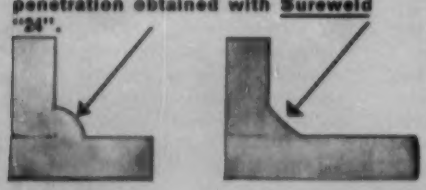
DO YOU USE E-6012 OR E-6020 FOR FILLET, LAP OR FLAT BEVEL WELDING?



A. Length (12.3") of ¼" fillet weld deposited by 3/16" Sureweld "24" electrode in one minute.

B. Length (9.8") of ¼" fillet weld deposited by next larger size—¼"—E-6012 electrode in one minute.

Typical cross-sections of welds made (A) by ¼" E-6012 electrode and (B) by 3/16" Sureweld "24" electrode. Note in (B) the smooth flat profile, the absence of undercutting and the deep penetration obtained with Sureweld "24".



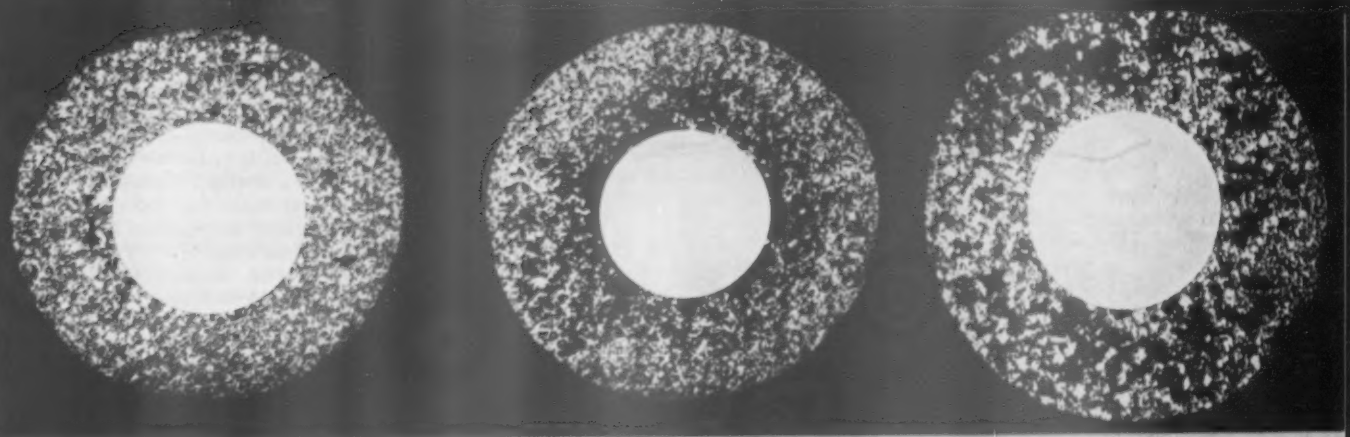
These new electrodes can boost your production welding, reduce your welding costs, give you better quality welds

Tests made under normal shop conditions show that the new *Sureweld* iron powder electrodes can lay down 25% more metal in a given time than E-6012 or E-6020. This is not only because of their faster burn-off rate but because of their higher efficiency. In making the tests, a 3/16" *Sureweld* "24" electrode was used as against *the next size larger*, E-6012. The 3/16" *Sureweld* rod produced 12.29 inches of fillet weld in one minute as against 9.78 inches for the ¼" E-6012. Cost per one foot of weld was $0.0756 for *Sureweld* "24". Cost per one foot of weld was $0.0818 for E-6012. These cost figures do not include savings from the use of lower amperages nor the savings from easier clean up, less grinding and finishing and the almost total elimination of undercutting.

Sureweld iron powder electrodes also produce *better welds* —with higher impact values and greater crack resistance, deeper penetration and remarkable freedom from porosity.

Two types of these new electrodes are available: *Sureweld* "24" (E-6024) for production welding applications in which E-6012 is now used; and *Sureweld* "27" (E-6027) for E-6020 applications.

Write—for new descriptive bulletin for a free demonstration or buy and try Sureweld Iron Powder Electrodes yourself at your authorized NCG dealer or NCG office



Cross-section of Sureweld "24" electrode. Note the even distribution of iron particles and other coating constituents.

Cross-section of a well known brand of iron powder electrode. Compare the uniformity with that of the Sureweld electrode.

Cross-section of still another well known brand of iron powder electrode.

DO YOU USE IRON POWDER ELECTRODES NOW?

These macrophotographs reveal facts vital to your welding profits

The one chief reason for using iron powder electrodes is to increase welding production and profits. But your success in the use of iron powder electrodes depends principally on how uniformly the iron powder particles and other ingredients are mixed in the coating. When the ingredients are mixed evenly, burn-off proceeds uniformly, evenly and swiftly; and you get maximum welding production.*

The macrophotographs shown above have been made by an independent and impartial testing laboratory of random cross-sections of a *Sureweld* iron powder electrode and two other well-known brands of iron powder electrodes. These magnified cross-sections reveal the distribution of iron powder particles and other constituents in the coating of the three brands of electrodes mentioned.

***NOTE: The welding process is a form of partial combustion. As in the case of all combustion, any man who has ever built a fire knows that "fuel" elements must be evenly distributed if the fire is to burn well and rapidly. But if there is uneven distribution and "dead" spots you have trouble getting the fire started and keeping it going. This is true of coated electrodes as well, especially those with powdered iron added to the coatings.**

Why Sureweld iron powder electrodes always possess complete uniformity

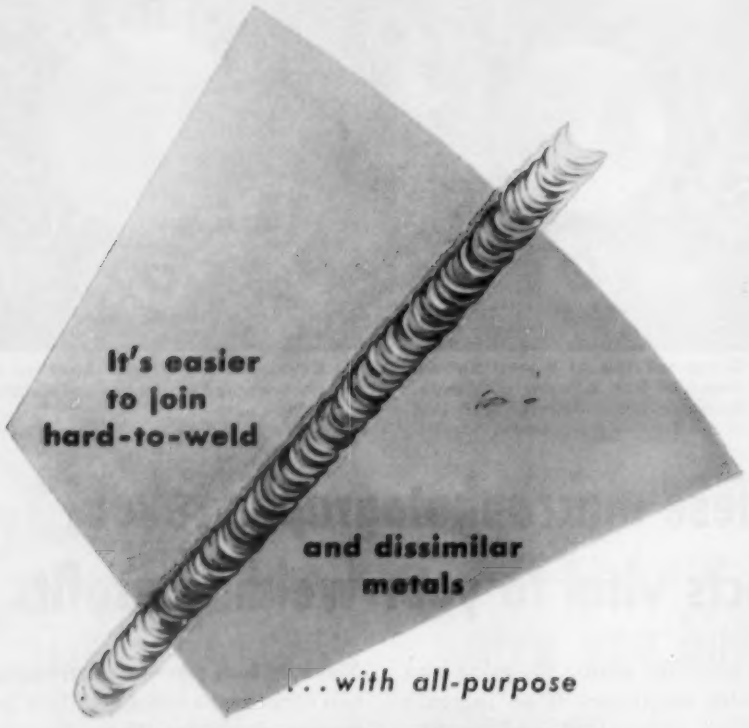
Efficient iron powder electrodes don't just happen. They are carefully planned and carefully made. NCG selects coating ingredients carefully and mixes them carefully. And instead of the conventional hydraulic extrusion equipment which exerts heavy pressure on the entire mass of flux, NCG uses special gear-type extrusion-coating machine which is shown on this page. Large screws feed the flux into synchronized gears that transfer the flux in small amounts to the extrusion chamber. *And only at the point of actual coating and extrusion is high pressure used, when it is too late to cause segregation of the flux ingredients.* Thus the uniformity arrived at in the flux-mixing machines remains unimpaired.

NCG®

EVERYTHING FOR WELDING

Copyright 1955, National Cylinder Gas Company

NATIONAL CYLINDER GAS COMPANY
840 NORTH MICHIGAN AVENUE
CHICAGO 11, ILLINOIS *Branches and Dealers from Coast to Coast*

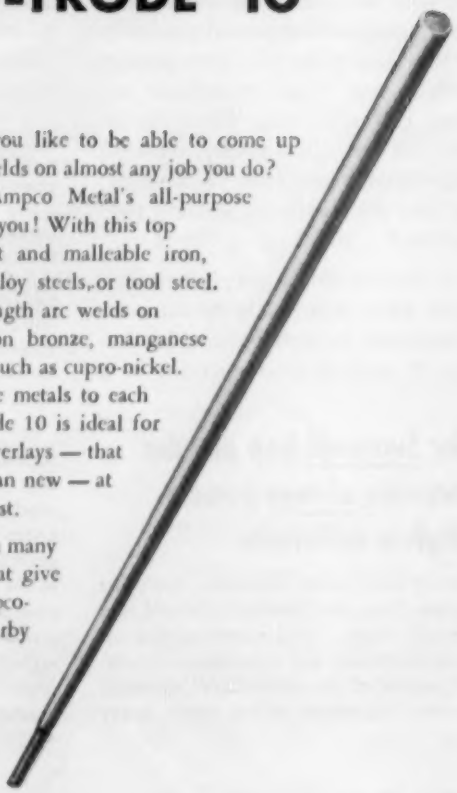


AMPCO-TRODE* 10

How would you like to be able to come up with dense, crack-free welds on almost any job you do? Ampco-Trode 10 — Ampco Metal's all-purpose electrode — does it for you! With this top performer you join cast and malleable iron, galvanized steel, high-alloy steels, or tool steel. You can make high-strength arc welds on aluminum bronze, silicon bronze, manganese bronze, or nickel alloys such as cupro-nickel. You can even join these metals to each other! And Ampco-Trode 10 is ideal for long-wearing bearing overlays — that make old parts better than new — at a fraction of new-part cost.

Get the upper hand on many difficult welding jobs that give you trouble. Order Ampco-Trode 10 from your nearby Ampco distributor or write us.

*Reg. U. S. Pat. Off.



AMPCO

Sole producer of genuine Ampco Metal

AMPCO METAL, INC.
Milwaukee 46, Wisconsin
West Coast Plant • Burbank, California

W-132

inert-gas welding, ac or dc, and they are ideal for automatic inert-gas welding, too. They can also be used for consumable-electrode inert-gas welding. Harnischfeger also states that the use of a spot-welding gun adapts them for fast, efficient spot welding.

Further information on these P&H ac/dc welders is available from the Welding Division, Harnischfeger Corp., Milwaukee 46, Wis.

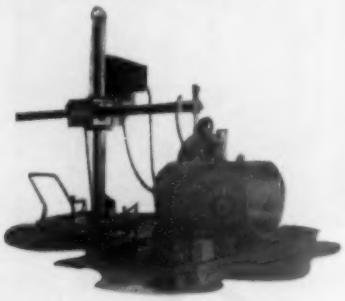
High-Speed Grinder

Through the development of a special method of processing abrasive coated cloth disks, New Era Engineering Co., 458 W. 29th St., Chicago 16, Ill., has produced a grinder which operates at a perimeter speed of more than 18,000 fpm (yes, more than 3 mph).

Known as the NEECO-2-TWENTY Abrasive Coated Cloth Disc. Grinder, the new unit is a 20-in. diam double disk machine. It is powered with a special 10 hp motor. It is direct driven, and supplied in 220 or 440 v, 60 cycle. Additional information can be obtained by writing to manufacturer.

Welding Head Manipulator

The Pandjiris Semi-Automatic Manipulator, introduced early in 1954, has undergone considerable changes, according to the manufacturer. The new version of SAM shows many refinements which were adapted after field experience with many models.



Further information may be obtained by writing the Pandjiris Weldment Co., 5151 Northrup Ave., St. Louis 10, Mo.

World's Largest Continuous

Safety Welding Shield

Frommelt Industries, Dubuque, Iowa call attention to their SPA-FLA Safety Welding Shields, whose design features are claimed to be ideally suited for portability, since they are light in weight, can be rolled and carried as a part of the welding equipment.

Specifications available on request to the manufacturer.

Fluxing System

An advanced automatic fluxing system for production and maintenance brazing operations, announced by All-State Welding Alloys Co., Inc., 249–255 Ferris Ave., White Plains, N. Y., meters liquid flux into the fuel gas according to size of brazing tip and regulator pressures. Ruggedly compact, simple and sized to carry a charge for a work-week of brazing operations, it may be attached to the individual welder's hand truck or to the fuel line at the production brazing station. For further information, write directly to manufacturer.

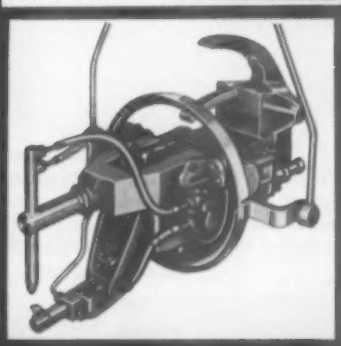
Acetylene Torch Outfit

Complementing their present line of LP-gas torches, Ransome Co. of Emeryville, Calif., has developed a new multi-purpose acetylene torch outfit.

The company states that the torch is an improved design which overcomes many of the inadequacies now prevalent in torches used in the plumbing, automotive repair, electrical, refrigeration, sheet metal, jewelry and other allied fields.

An illustrated catalog sheet and price list may be had from Ransome Co., 4030 Hollis St., Emeryville, Calif.

BOOTH 276
Kansas City, June 8-10
WELDING SHOW



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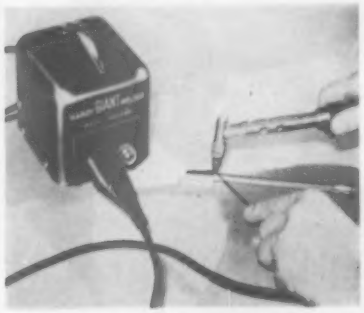
PORTABLE SPOT WELDERS
• With And Without Automatic Timer.
• Adjustable Pressure
• High Duty Cycle
Dealer Inquiries Invited
AIR & WATER COOLED MODELS
ARO SPOT WELDERS INC.
87 Hamilton Pl. N.Y. 31, N.Y.

Weld-Solder Unit

The Cauhorn Manufacturing Corp. announces the introduction of a unit using only 6 v, and operating 115-v, 60-cycle a-c house current; also from car, truck, tractor or boat batteries. It is light in weight and is claimed to be satisfactory for easy welding, brazing and soldering.



Complete details may be had by writing to: Cauhorn Manufacturing Co., 9999 Broadstreet, Detroit 4, Mich.

The Champ of Clamps!

THE GRAND DUAL GRIP TYPE "AS"

Quick setting double-action clamp grips work more securely. Holds irregular and off-parallel surfaces as well as flat work due to pincer action. Easily tightened in cramped areas.

4 SIZES: 2½" TO 6" OPENING
SPATTER-PROOFED—NACO NO. 6 STEEL
(80,000 LBS. TENSILE)

Famous GRAND "C" Clamps
Alloy Steel (Stronger than forged) Spatter-Proofed Screws, Deep Throat—Replaceable Swivels

LIGHT SERVICE SERIES — L SERIES — 8 SIZES 2" TO 12"
MEDIUM SERVICE SERIES — ASM SERIES — 7 SIZES 4" TO 18"
HEAVY SERVICE SERIES — ASH SERIES — 8 SIZES ¼" TO 12½"

NCG
STOCKED and DISTRIBUTED BY NATIONAL CYLINDER GAS COMPANY
Offices in Principal Cities

exposing defects, such as slag inclusions,

powerize
your welding job for
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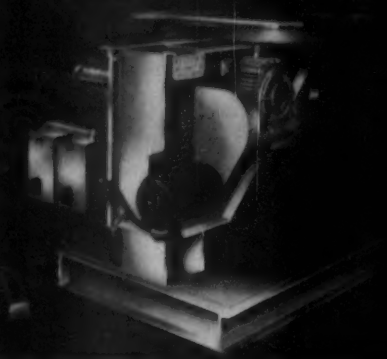
pandjiris positioners



. . . POWER to tilt your weldments 135° and rotate them 360° for downhand welding. . . . every feature that can make a positioner easy to work with — rugged — stable . . . is built-in by Pandjiris. Available in *capacities up to 140,000 lbs.* 3,000 lb. model shown.

pandjiris turning rolls

See you at Booth 245 Kansas City Welding Show June 8-10

. . . POWER to turn cylinders continuously for circumferential seams . . . to position them for horizontal welds. No crane or manual work!

Pandjiris builds 'em right . . . in *capacities up to 400,000 lbs.*

THE WORLD'S LARGEST MANUFACTURERS OF "AUTO-WELD-MATONS" ®

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pandjiris weldment co.

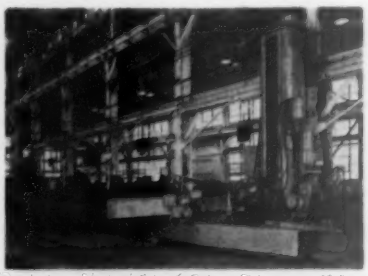
DESIGNERS AND MANUFACTURERS OF PRODUCTION WELDING EQUIPMENT

efficient positioning of all three

World's Largest Continuous Welder

The world's largest continuous welder now at work for the Morgan Engineering Co., Alliance, Ohio, reportedly reduces costs and the time of welding girder seams as much as 94%.

The welder with a track length of 110 ft can obtain speeds of up to 120 ipm.



The unit has two welding heads that float both vertically and along the ram horizontally. The welding heads will trace curves and follow a change in direction around a girder flange, allowing two seams of a girder to be welded at one time. The welder can also accomplish the welding of both girth seams of hoisting drums at one time.

The welder, designed and developed by the Morton Manufacturing Co., of Muskegon, Mich., and Morgan, is claimed to be the only one of its kind in the world.

Weld-Prober

Weld-Prober, developed by The Fibre-Metal Products Co., enables a positive check of a weld and of the welder's workmanship.

The Weld-Prober is a machine for cutting out specimens from butt-welded joints to examine the quality and soundness of the weld. Specimens give an account of the workmanship of joint by

exposing defects, such as slag inclusions, lack of fusion, cracks and porosities. Physical and mechanical properties of joint can also be determined by machining the cutout specimens into tensile, bending, impact or other forms of test pieces.

A great advantage of this test consists in the favorable shape of the cavity produced in the joint. This opening can be quickly and easily rewelded without further preparation and without a backing plate.

The cutting operation is accomplished by a thin spherical saw driven by a fractional horsepower motor and reduction gear. This unit is articulated at spherical center of the saw, the hinge points being located on a swivel. The swivel revolves on a mounting frame and can be secured to it in any desired position by a clamping device.

For further information, write directly to the Fibre-Metal Products Co., Chester, Pa.

For an answer to your practical welding problems, attend
WELDING CONFERENCES
Municipal Auditorium
Kansas City, Mo.
June 8-10

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The most revolutionary achievement in arc welding equipment in years!

Patent Pending

Dimensions: only 11" x 12" x 7½"

BREN-WELD MODEL 200 AW

FIRST TRULY PORTABLE 200 AMP. OUTPUT ARC WELDER

Weighs only 65 lbs . . . Carry it to the job!

OBSOLETES ALL OTHER WELDERS OF COMPARABLE RATING

Sensational new transformer development produces far more power to pound! The BREN/WELD does work of conventional welders 4 or 5 times its size and weight . . . Actually delivers up to 250 amps at reduced duty cycle.

Simple to use, fully guaranteed, it operates on 110/220 volts AC, 50/60 cycles; handles electrodes from 3/64" to 5/32". Has adjustable arc voltage for different arc characteristics. Ideal for plant production and maintenance, for construction work, railroads, on farm or home.

List Price $169.50 F. O. B. Long Island City, N. Y.

See your dealer or write direct for details of free trial offer!

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Integrity Since 1919
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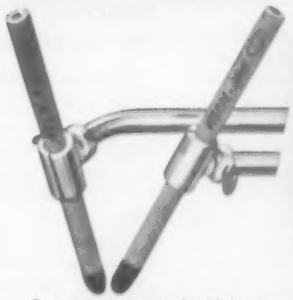
BECKER

KEEN-ARC CARBONS



FOR CONSISTENTLY GOOD RESULTS

Designed to carry the high currents necessary for intense heat, BBB Keen-Arc Carbons produce a fine-grained weld of high tensile strength. They give a smooth, steady "flowing" flame which does not wander and which is concentrated at the desired focal point. Flame temperature is easily and accurately adjusted by merely changing the ampere input, and heavy copper coating permits gripping at extreme ends—eliminates frequent and periodic resetting.

A COMPLETE LINE OF CARBON WELDING SUPPLIES including carbon and graphite electrodes, carbon rods and plates, welding paste, etc. Write for catalog.

BECKER BROTHERS CARBON CO.
3450 South 52nd Ave. Cicero 50, Illinois

NEW LITERATURE

Electrode Chart

Ampco Metal, Inc., has compiled an up-to-date Bronze Electrode Comparative Chart (54D-203) listing all known brands of aluminum bronze, phosphor bronze, nickel-aluminum bronze and manganese bronze electrodes on the market for use in electrode selection.

Copies of this chart are available upon request from Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Wedge Bars

Actual-size illustrations of Manganal Wedge Bars are featured on a 24- x 36-in. wall chart, being made available by the Stulz-Sickles Co. According to this manufacturer, it is a simple matter to determine the correct wedge bar to be used in rebuilding any worn tooth by direct comparison to the full-size illustrations.

Twenty-three different sizes of Manganal 11–13½% Manganese-Nickel Steel Wedge Bars are shown.

Also listed are complete dimensions and estimated weights of Manganal 11–13½% manganese-nickel steel flat, round and square applicator bars.

Specifications for Manganal hot-rolled plates, available in seven thicknesses and several stock sizes, are included.

The Manganal Wall Chart is claimed to be a valuable working aid for any welding shop, and it is free for the asking. Write for it to: Stulz-Sickles Co., Newark 5, N. J.

Powder Spraying Unit

A new 4-page, 2-color, 8½ x 11, illustrated bulletin describing the new Model C Spraywelder and the Sprayweld process is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich. The Spraywelder is a metal powder spraying unit used in welded overlay type hard-facing applications.

The new bulletin describes the Spraywelder and the Colmonoy alloys available for use with the new Model C which has greater spraying capacity and deposit efficiency than previous models. Included is a detailed explanation of the three basic operations in the Sprayweld process (preparation, spraying and fusing) as well as photos showing specific applications in which Colmonoy hard facing has solved serious wear and corrosion problems.

A list of typical Sprayweld applications is provided.

Equipment Directory

Directory of Welding and Fabricating Equipment. Section I: Metal Arc Welding Electrodes. Published by the Louis Cassier Co. Ltd., Dorset House, Stamford St., London, S.E. 1. in December 1954. Reprinted from *Welding and Metal Fabrication.* Size 11½ x 8½ in. 35 pp. Price, 3*s.* 6*d.* (by post 3*s.* 9*d.*).

Contents: Part 1—"Electrodes for Welding Mild Steel." Part 2—"Electrodes for Welding Alloy Steels." Part 3—"Electrodes for Hardfacing." Part 4—"Electrodes for Welding Cast Iron." Part 5—"Electrodes for Welding Non-Ferrous Metals."

According to the publisher, this is a comprehensive guide to the entire range of electrodes now available in the United Kingdom. Engineers may see at a glance details of each British electrode for welding any of the metals at present used in the fabricating industries.

Directory of Testing Laboratories

The American Society for Testing Materials has just published its "Directory of Commercial and College Testing Laboratories" which is a successor to a similar publication formerly published by the National Bureau of Standards of the U. S. Dept. of Commerce.

The Directory lists the locations of testing laboratories equipped and prepared to undertake testing on a commercial or fee basis. Information is given concerning 278 commercial testing laboratories and their 151 branches or offices. There is also presented a list of the laboratories of 86 colleges that are prepared to do testing under certain conditions. Research and consulting laboratories are not listed unless they also are engaged in testing on a commercial basis.

The Directory is designed to be of assistance to purchasers not equipped to make their own tests, and who therefore have hesitated to buy on specifications.

Copies may be purchased from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa. 48 pp., 8 x 10½, paper cover. Price $1.00.

New Brazing Manual

The Air Reduction Sales Co. has announced the availability of a new 24-page brazing manual. This manual is especially concerned with the application of the major brazing methods in joining metals using silver alloys and filler metals, fluxes and gas atmospheres.

Request a copy of the new "Brazing Manual" by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Ampco Electrodes and Rods

Ampco Metal, Inc. has released a new Bulletin 54L-148 describing Ampco-Trode 46 electrodes and filler rods in detail.

Ampco-Trode 46 is a new, nickel-aluminum bronze alloy available as covered electrodes for metal-arc and 36-in. bare filler rods for inert-gas tungsten-arc and covered 36-in. filler rods for the carbon-arc welding of castings of a similar composition.

For a copy of this bulletin, write to Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

Preheating Chart

The Tempil° Preheating Chart lists in a clear, concise manner the recommended preheat temperatures for 79 commonly used metals and alloys. Plain carbon steels, high-tensile steels, medium chrome moly steels and plain chrome steels are some of the metal groups for which approximate compositions and recommended preheat temperatures are shown. Factors influencing temperatures and the desirable effects of correct preheating on metal properties are enumerated.

Copies may be obtained, free of charge, by writing to Tempil° Corp., 132 W. 22nd St., New York 11, N. Y. Requests should preferably be made on business letterheads.

Stud Welding

keep an eye on*

PROGRESSIVE*

It's the BEST way to know about the IMPORTANT ADVANCES in RESISTANCE WELDING and AUTOMATION

PROGRESSIVE'S continuing program of new product development is the reason that America's forward looking manufacturers *check with Progressive first* when it comes to fastening and joining problems.

For over 20 years, PROGRESSIVE WELDINEERING KNOW-HOW has slashed costs, improved product appearance and increased production in all types of plants.

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BRAZING AND HEAT TREATING ALUMINUM
This EF furnace advances assemblies through three separate chambers for brazing and solution treating. Built by The Electric Furnace Co., Salem, Ohio.

COPPER BRAZES AND BRIGHT ANNEALS
Steel assemblies are discharged from this EF furnace securely brazed, undistorted, bright and ready to use. Built by The Electric Furnace Co., Salem, Ohio.

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This EF gas fired furnace will handle above and other processes at temperatures up to 2050° F. Built by The Electric Furnace Co., Salem, Ohio.

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We build production equipment for heat treating ceramics and metal products in any shape or form. We build the furnace to fit the job.
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THE ELECTRIC FURNACE CO.
Salem - Ohio

Stud Welding

Stud Welding Standardized Specifications: 16-page booklet covering ordering and engineering data of 12 most commonly used studs. Also review of applications and equipment. KSM Products, Inc. (Stud Welding Division), Merchantville 8, N. J.

Hard Surfacing

The Rankin Manufacturing Co. announce the availability of their eight-page catalog on Ranite hard-surfacing materials. Write for free copy to this company at 3072 W. Pico Blvd., Los Angeles 6, Calif.

Westinghouse Welding Process

The performance and applications of new consumable electrode inert gas welding process — West-ing-arc — are given in a new booklet available from the Westinghouse Electric Corp. This 7-page booklet answers the questions: What is West-ing-arc? What can it do? Where can it be used? What are the operating costs? What are the components?

For a copy of this booklet, B-6525, write Westinghouse Electric Corp. P.O. Box 2099, Pittsburgh 30, Pa.

Arcair Booklet

Arcair Co., 423 S. Mt. Pleasant Ave., Lancaster, Ohio, announces the publication of a new Case History Booklet, which shows many detailed on-the-job reports on the use of their Arcair cutting and gouging torch. This booklet is offered free to any company or individual interested in learning more about the unique and exclusive Arcair process of metal removal, using only an electric arc and compressed air.

Cast Weld Construction

Reprint of a technical article entitled "Cast-Weld Construction of High-Alloy Steel Parts" is now being offered by the Cooper Alloy Corp., Hillside, N. J. The article discusses in detail the field of application for cast weld techniques. It elaborates on improving the soundness of complicated castings and points to economies that may be realized. Diagrams are freely used in the article to clarify various techniques in the application of cast-weld construction.

Copies are available on request to Cooper Alloy Corp.

Deoxidizing Agents

Stronger, more uniform resistance welds on aluminum and aluminum-alloy surfaces are now possible at lower cost, reports the Diversey Corp. Using a four-step process containing Diversey No. 808 and Diversey No. 514 more consistent welds with greater shear strength can be obtained with increased electrode tip life.

For descriptive literature write to: The Diversey Corp., Metal Industries Department, 1820 Roscoe St., Chicago 13, Ill.

Welding Machines

A new 54-page, spiral bound, $8^1/_2$- by 11-in. comprehensive catalog describing the company's wide variety of welding machines, automation machines and special machine tools is now available from Expert Welding Machine Co., 17144 Mt. Elliott Ave., Detroit 12, Mich.

Forty-six individual types of automatic welders for submerged-arc, resistance and inert-arc welding operations are described and illustrated in the catalog. Automatic assembly and automatic nut torquing machines are described with photographs in the automation machine section of the catalog.

Eye-Protective Equipment

Many new developments in eye-protective equipment are included in the complete, revised catalog of "Eye Savers" products just released by Watchemoket Optical Co. Among the new products, is an opaque black, soft vinyl frame Welding Goggle.

The manufacturer states that the revised catalogs are available from authorized "Eye Savers" jobbers and distributors in all principal cities, or from Watchemoket Optical Co., 232 W. Exchange St., Providence 3, R. I.

Champion "Croloy" Electrodes

The Champion Rivet Co., of Cleveland, Ohio, announces a new line of low-alloy steel arc-welding electrodes for the welding of chromium molybdenum alloy steels. These electrodes are of the lime ferritic, AWS XX15 type, and are suitable for all position welding, when using direct current, reverse polarity. They have been designated as Champion Croloy Electrodes.

A copy of Bulletin 55CM which fully describes the properties of these electrodes and their application is available from the Champion Rivet Co., 10817 Harvard Ave., Cleveland 5, Ohio.

Grinding Safety Pamphlet

Better Welding!

ONE TOUGH JOB
—three magnet frame pieces of different thicknesses, projection welded in one operation

Improved non-synchronous performance with Square D's NEW SLOPE CONTROL

Heat—
Up & Down
Slope

BETTER AND MORE PROJECTION WELDS through more uniform distribution of welding current.

PERMITS WELDING NON-FERROUS METALS. Reduced "spitting" at electrodes improves appearance of aluminum and other non-ferrous welds—extends electrode life.

DESIGN FEATURES

Matched Enclosures. Slope Control enclosure matches Square D Non-Synchronous Welder Controller (Nema N2), shown at right. Also matches individual Square D welding timer or contactor enclosures.

Simplified Circuit, standard components, and heavy-duty construction.

Write for Bulletin 8990 EWG. Address Square D Company, 4041 North Richards Street, Milwaukee 12, Wisconsin.

SQUARE D COMPANY

HIGH GAIN INDUSTRIAL
POCKETSCOPE
by Waterman

MODEL S-14-A

DC COUPLED
10 mv/inch
½ CYCLE SWEEP

Size: 12" x 6" x 7"
12¼ Pounds

ANOTHER EXAMPLE OF Waterman PIONEERING...

The HIGH GAIN POCKETSCOPE, model S-14-A, is an outstanding achievement in the field of oscilloscopes. The high vertical and horizontal sensitivities of 10 and 15 millivolts rms/inch respectively; frequency responses within —2 db from DC to 200 KC; non-frequency discriminating attenuators and gain controls; plus individual calibration voltages are but a few of the heretofore unobtainable characteristics of DC coupled oscilloscopes. The sweep is operated in either a repetitive or trigger mode over a range from 0.5 cycles to beyond 50 KC with synchronization polarity optional. All this and portability too! The incredibly small size and light weight of the S-14-A now permits "on-the-spot" use of the oscilloscope in all industrial, medical, and electronic fields. Its rugged construction assures "laboratory performance" regardless of environment.

WATERMAN PRODUCTS CO., INC.
PHILADELPHIA 25, PA.
CABLE ADDRESS: POKETSCOPE

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S-4-C SAR PULSESCOPE®
S-5-A LAB PULSESCOPE
S-6-A BROADBAND PULSESCOPE
S-11-A INDUSTRIAL POCKETSCOPE®
S-12-B JANized RAKSCOPE®
S-14-A HIGH GAIN POCKETSCOPE
S-14-B WIDE BAND POCKETSCOPE
S-15-A TWIN TUBE POCKETSCOPE
RAYONIC® Cathode Ray Tubes
and Other Associated Equipment

Grinding Safety Pamphlet

The Safety Committee of the Grinding Wheel Institute, recognizing the need for proper operator education in the safe use of grinding wheels, has issued a simple and concise four-page pamphlet entitled "Safety Guide for Grinding Wheel Users." Copies of the pamphlet may be obtained, free of charge, by writing the Grinding Wheel Institute, 2130 Keith Building, Cleveland 15, Ohio.

Stud Welding

A 6-page folder detailing methods for the stud welding of standard concrete anchors for curbing, column guards, protective platform installations, door frames and other fabricated architectural components, as well as for bridge expansion dams and other structural applications, has been published by the Nelson Stud Welding Division of Gregory Industries, Inc., Lorain, Ohio.

In addition to complete information on the standard types and sizes of studs recommended for various purposes it carries detailed drawings of more than 20 different applications, as well as catalog information on equipment suitable for shop or field use. Write to manufacturer for your copy.

Safety Equipment

The 1955 issue of "Everything in Safety," a catalog of personal protective equipment and industrial safety devices, has just been released by the General Scientific Equipment Co., 2700 W. Huntingdon St., Philadelphia 32, Pa. It covers respiratory devices, eye protection, hats, gloves and other miscellaneous industrial safety equipment. It is 130 pages, fully illustrated. Copy sent free on request.

MEMBERS RECLASSIFIED

(*Continued from page 492*)

CINCINNATI

Schauerte, Gerald E. (C to B)

LOS ANGELES

Yeoman, Arthur E. (C to B)

NEW JERSEY

Thornton, Robert V. (C to B)

NORTH CENTRAL OHIO

Woodward, Vincent L. (C to B)

NORTHERN NEW YORK

Gerken, John M. (D to C)

SAN FRANCISCO

Anderson, E. E. (C to B)
Thylin, Elmer C. (C to B)

YORK CENTRAL PENNSYLVANIA

Cassaboom, Gordon E. (D to C)

Current Welding Literature

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SUPPLEMENT TO THE WELDING JOURNAL, MAY, 1955

EFFECT OF WELDING ON TRANSITION TEMPERATURE OF NICKEL STEEL PLATE

Welding does not appreciably lower the transition temperature of low-carbon, 3½% nickel steel plate, particularly if welds are stress relieved

By T. N. ARMSTRONG and W. L. WARNER

The use of low-carbon nickel steel plate for pressure vessels intended specifically for service at low temperatures dates back some twenty-odd years and initially was associated with petroleum processing. The applications were for dewaxing lubricating oils and involved use of temperatures down to −50° F. Later, low temperatures were applied also for dewaxing liquid propane and, more recently, low temperature processing has been used extensively in the fractionation and liquefaction of gases. Currently, temperatures down to that of liquid nitrogen are not uncommon and even lower temperatures are involved in liquefaction of some of the light gases.

The nickel steel used initially contained up to about 0.20% carbon and approximately 2½% nickel. Suitability for low temperature service was based upon the ability of the steel to meet a minimum notch-bar impact value. The keyhole-notch-Charpy specimen was selected after some study and, despite the continuing controversy ever since over the type specimen and the inability to apply impact properties to design, the keyhole-notch-Charpy test still is used as the criterion to determine the suitability of pressure vessel steels for low temperature service. Also, it is interesting to note that there has been little change in the numerical values required since low temperature testing requirements were first introduced into materials specifications. The authors, however, are neither defending nor attacking the use of the keyhole-notch-Charpy test and neither are they entering the controversy on whether 15 ft-lb should be selected to represent the transition from ductile to brittle behavior. It must be recognized, however, that so long as standard specifications and codes require 15 ft-lb Charpy, keyhole notch, this value will be accepted as the criterion for pressure vessel steels for low temperature service.

When nickel steel plate first was supplied for low temperature service the impact results varied considerably from heat to heat. After it became apparent that deoxidation practice and grain size had appreciable affect on impact properties, practices were adopted that would insure consistent results. As the temperatures of processing were lowered it became necessary to increase the nickel content of the plate to meet the impact requirements at the lower service temperatures, and as a result a 3½% nickel grade came into use. The 3½% nickel steel is used for temperatures as low as −150° F and because of its greater availability it has gradually displaced the lower nickel grade even for temperatures between −40 and −100° F when less than full heat lots of plate are required.

There has been considerable information published[1] on the impact properties of low-carbon, 3½% nickel steel plate and there is sufficient background of use to prove its usefulness at temperatures down to −150° F. In fact, there is no record of failure when the steel was used in pressure vessels which operated at temperatures not much below −150° F. The inclusion of the steel in ASTM Specification A300 and in Table UC8-23 of

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This paper is to be presented at the AWS National Spring Meeting to be held in Kansas City, Mo., June 7-10.

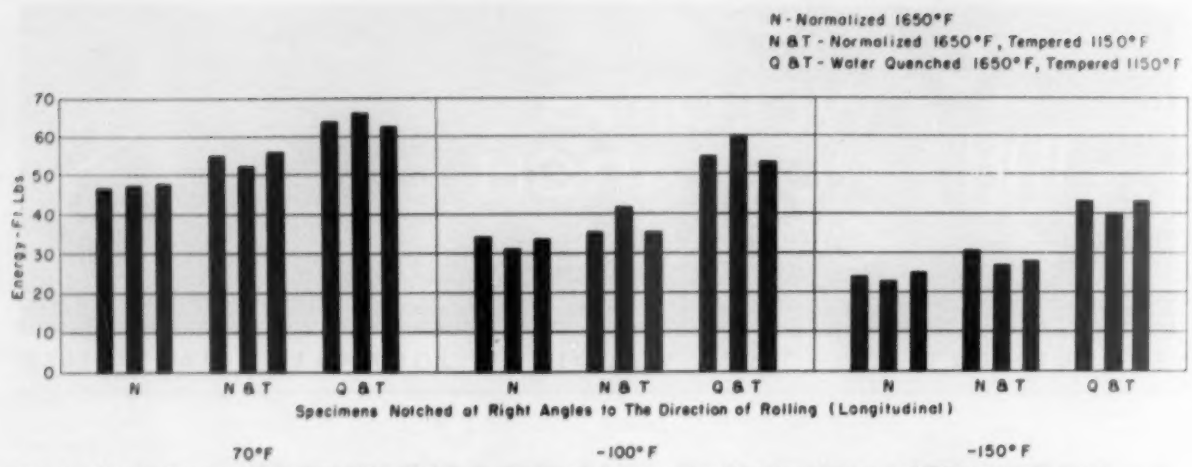

Fig. 1 Effect of heat treatment on Charpy impact properties (keyhole notch) of low-carbon, $3^1/_2\%$ nickel steel plate

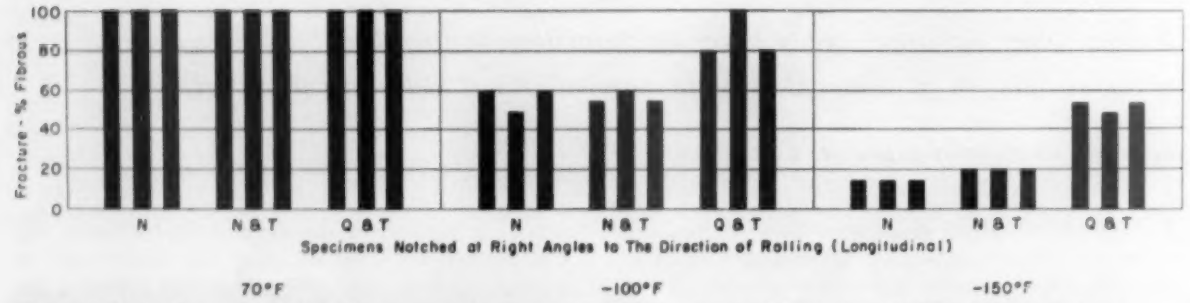

Fig. 2 Effect of heat treatment on fracture appearance of Charpy specimens of low-carbon, $3^1/_2\%$ nickel steel plate

the Unfired Pressure Vessel Code indicates general acceptance.

Results of many research investigations undertaken during the past several years have added to the knowledge of the effect of composition and methods of processing on the transition temperature. The designer now can select a steel, whether it be carbon, low alloy or high alloy, for a low temperature application and have some confidence that the material will meet a Charpy value of 15 ft-lb, providing the accepted low temperature limits for the specific material are not exceeded. Recently, more attention has been directed toward the effect of design features and fabricating operations on the transition temperatures of complete structures as it is becoming more generally recognized that a specific transition temperature of a component, such as a plate, does not assure the same transition temperature in a complete structure, such as a pressure vessel, constructed from the plate. Fabricating processes, such as welding and cold forming, add to the complexity of the problem.

Details of Test

The results reported herein were obtained from a study of the effect of welding on the low temperature impact properties of nickel steel plate. One-inch thick plate of low-carbon, $3^1/_2\%$ nickel steel, conforming to Grade D of ASTM Specification A 203–53 T and Class 3 of ASTM Specification A 300–53 T, was used in all tests. Composition and tensile properties of the normalized plate were as follows:

Stock	*C, %*	*Mn, %*	*P, %*	*S, %*	*Si, %*	*Ni, %*	*Yield point, psi*	*Tensile strength, psi*	*Elongation in 2 in., %*
A	0.15	0.57	0.013	0.018	0.15	3.39	56,600	76,800	29
B	0.12	0.56	0.018	0.033	0.16	3.48	53,400	73,200	27

NOTE. All tests were on plate from stock A except in the case of two Kinsel tests as indicated.

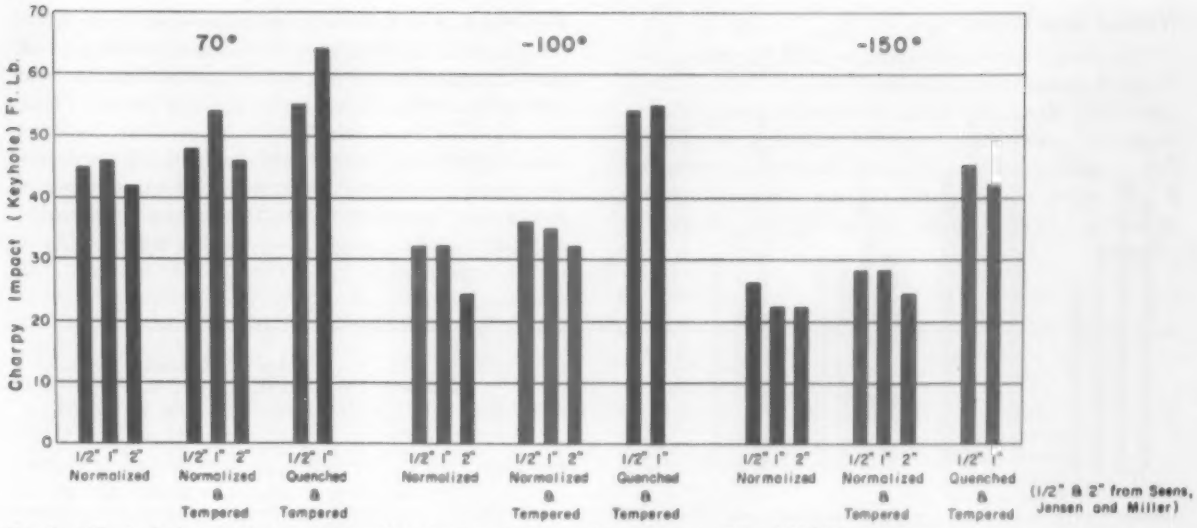

Fig. 3 Effect of plate thickness and heat treatment on Charpy impact properties of $3^1/_2\%$ nickel steel

Charpy impact tests, keyhole notch, were made at room temperature and at successively lower temperatures until decided embrittlement was encountered. Impact values were then plotted against temperature and a faired curve was projected through the points for each series. In addition, the fractured surfaces of the broken impact specimens were examined and the percentage of shear or fibrous area (ductile) recorded as compared to the cleavage area (brittle). The percentage of ductile fracture was then plotted against the test temperature.

Because of the many different ways of interpreting energy-temperature transition curves and also because the limiting low temperature has been generally established as $-150°$ F for low-carbon, $3^1/_2\%$ nickel steel plate, it was decided to limit comparison of test results to the three temperatures of 70, -100 and $-150°$ F. In most cases, tests were made at these specific temperatures but the values for comparison were taken from the curves.

The effect of different heat treatments on the impact properties of the plate at the three test temperatures is shown in Fig. 1, and in Fig. 2 the comparison is made on the basis of fracture appearance. As has been pointed out many times in the literature, there is a definite relation between a specific impact value and the fracture appearance for a specific steel.

Increase in thickness of steel plates generally will cause a lowering of impact values. Suitable material was not available in this investigation to study the effect of increasing plate thickness but by using values reported in the work of Seens, Jensen and Miller[2] to supplement these test data, the results shown in Fig. 3 were obtained. Obviously, it would have been preferable to make the comparison on plates from the same melt; however, such data are not available and it is believed that Fig. 3 gives a fair approximation of the mass effect within the limits selected.

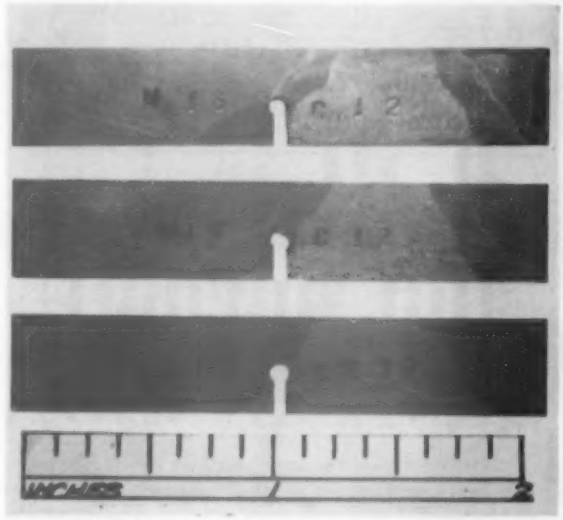

Fig. 4 Showing location for notch with respect to weld in welded Charpy specimens of $3^1/_2\%$ nickel steel

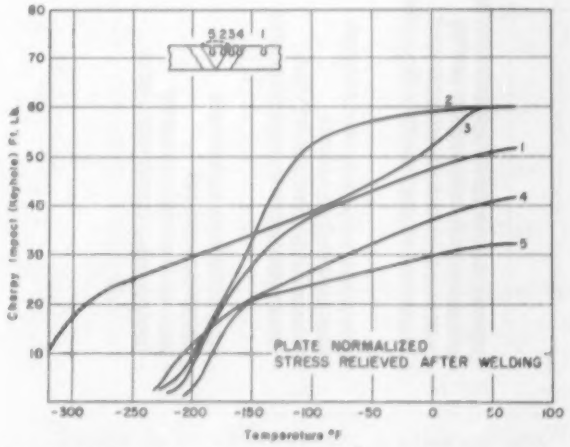

Fig. 5 Group of impact curves for one condition of welding and heat treatment of $3^1/_2\%$ nickel steel plate

Welded Specimens

The welded specimens were prepared by joining two pieces of nickel steel plate, each 1 x 5 x 15 in., with a butt weld along the 15-in. dimension, using $^3/_{16}$-in., electrodes conforming to AWS classification E8015. Weld metal deposited by these electrodes contained $3^1/_2$% nickel. The composition and tensile properties of the weld metal from two lots of the electrode were as follows:

Lot	*Condition*	*C, %*	*Mn, %*	*Si, %*	*Ni, %*	*Yield point, psi*	*Tensile strength, psi*	*Elongation in 2 in., %*	*Reduction of area, %*
A	As-welded	0.04	0.64	0.28	3.54	75,000	86,000	30	71
	Stress relieved	..	..	..	..	75,000	81,500	30	71
B	As-welded	0.06	0.76	0.42	3.41	64,000	87,000	27.5	68
	Stress relieved	..	..	..	..	75,000	87,000	25	67

The long axis of each weld was transverse to the direction of rolling of the plate. Specimens for impact test were machined out of the welded pieces with the weld approximately in the center of the test piece. These pieces, which were considerably longer than standard impact specimens, were machined to 0.394 in. square and then subjected to a light etch to bring out details of the weld and weld heat-affected zone. The exact position for the bottom of the notch was located, a

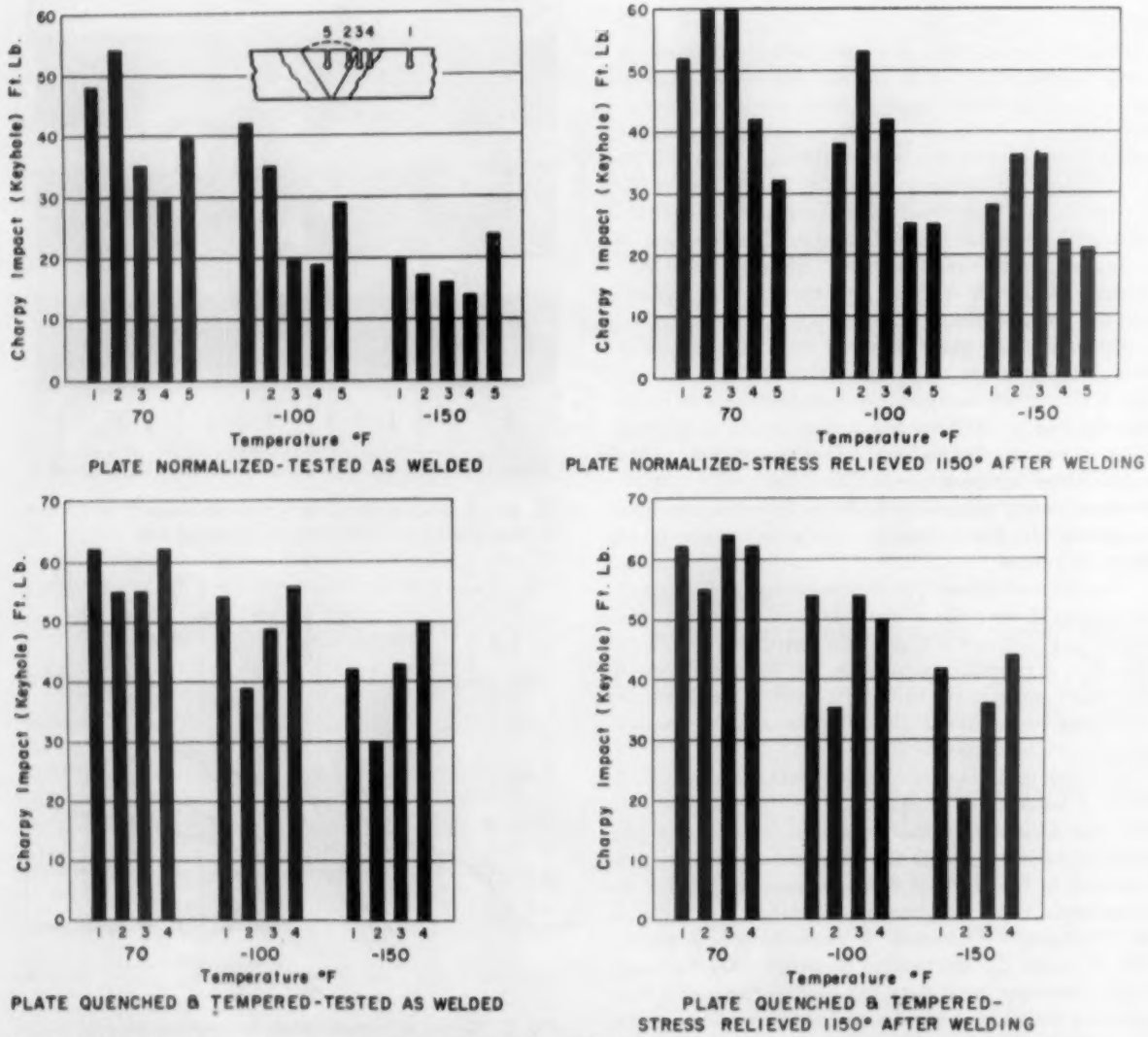
Charpy Impact (Keyhole) Ft. Lb.
5 2 3 4 1
1 2 3 4 5
70
-100
-150
Temperature °F
PLATE NORMALIZED-TESTED AS WELDED
PLATE NORMALIZED-STRESS RELIEVED 1150° AFTER WELDING
1 2 3 4
PLATE QUENCHED & TEMPERED-TESTED AS WELDED
PLATE QUENCHED & TEMPERED-STRESS RELIEVED 1150° AFTER WELDING

Fig. 6 Effect of welding on impact properties of low-carbon, $3^1/_2$% nickel steel

punch mark made and the specimen then was placed in a jig for drilling and cutting to length. In Fig. 4, three different specimens are shown, each with the bottom of the notch in a different location in relation to the weld.

A thorough study had been made of the effect of temperature on the impact properties of $3^1/_2\%$ nickel steel weld metal in a previous investigation[3] so only a few spot check tests were made of the weld metal. This left four locations that were believed to have significantly different structures. These were the interface between the weld metal and the base plate, the center of the heat-affected zone of the base plate, the outer edge of the heat-affected zone of the base plate and the base plate unaffected by the welding operation. The specimens notched at locations well away from the weld could be considered as the controls, as it is the values from these that are used as the basis for comparison.

Tests were made on specimens representing four different welded conditions as follows:

Plate normalized, welded, specimens tested as welded.
Plate normalized, welded, stress relieved.
Plate water quenched and tempered, welded, specimens tested as welded.
Plate water quenched and tempered, welded, stress relieved.

A complete temperature-energy transition curve was plotted from results obtained from testing specimens with the bottom of the notch located at the interface of the weld metal and the heat-affected zone for the normalized and welded plate. A fracture-temperature transition curve was plotted for the same specimens. Curves also were plotted from results of tests with the bottom of the notch in the center of the heat-affected zone, in the outer edge of the heat-affected zone and in the unaffected area.

This same series of tests was made on each of the other three welded pieces. A family of curves representing test results from one set of welding conditions is shown in Fig. 5.

The impact properties in different locations of the welded area were compared at temperatures of 70, −100 and −150° F. The influence of location of the notch with respect to the weld on impact properties is shown in Fig. 6 for each of the four conditions. The values used for Fig. 6 are replotted in Fig. 7 to show more clearly the effect of prior treatment and of stress relief at each location tested.

The same type of plotting as in Fig. 7 was used in Fig. 8 for fracture appearance. It will be noted that comparison is made on the basis of two different values for fracture transition, namely 95% shear fracture which in most cases was at the upper inflection point of the fracture-temperature curve; and at 20% shear fracture, which generally occurs at temperatures where corresponding Charpy values are slightly above 15 ft-lb.

Slow-Notch Bend Tests

The Charpy values obtained at any specific location in the welded area reflect the influence of a specific

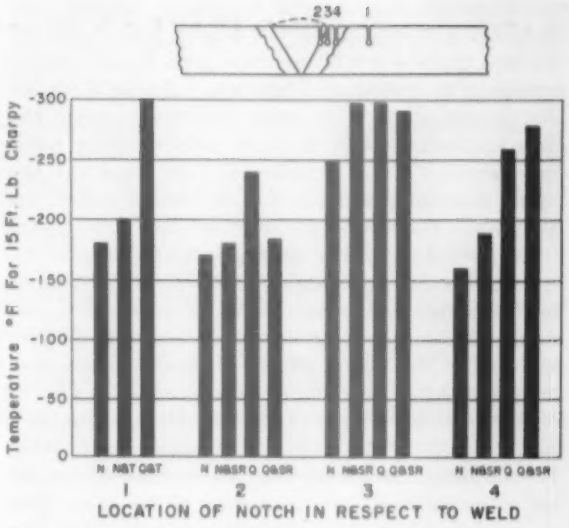

Fig. 7 Effect of prior treatment and stress relief on energy transition of $3^1/_2\%$ nickel steel

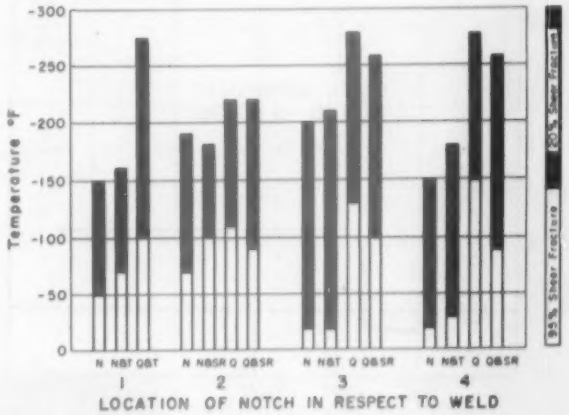

Fig. 8 Effect of prior treatment on fracture transition of $3^1/_2\%$ nickel steel

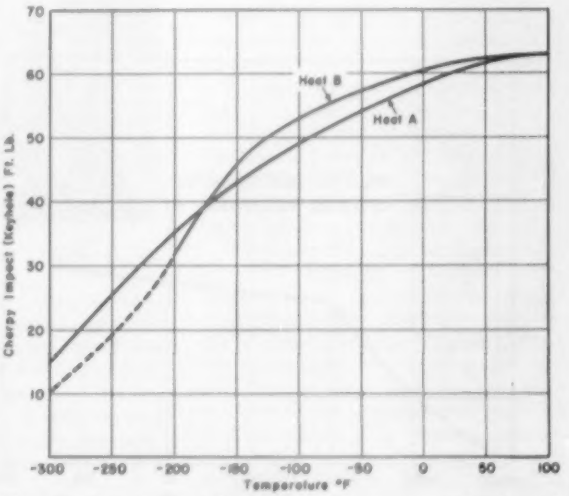

Fig. 9 Temperature-impact curves for quenched and tempered specimens from two heats of $3^1/_2\%$ nickel steel

microstructure but do not necessarily indicate the transition temperature of the welded joint. Several different types of notch tests have been devised for determining the transition temperature of a weld but for this investigation tests were conducted using the Kinzel specimen with a single bead-on-plate weld. Specimens 1 x 3 x 12 in. were cut from plate with the rolling direction parallel to the longitudinal axis of the specimen. The specimens were welded with $^{5}/_{16}$-in. nickel steel electrodes of the type used throughout the investigation, using a single longitudinal bead 8-in. in length on the plate, after which the standard Kinzel notch was machined across the specimen 4 in. from each end. The current was 200 amp and the speed of travel of the electrode was 6 ipm.

There was not sufficient plate from Heat A to make a Kinzel test for each of the four conditions of welding. The normalized and welded and the normalized, welded and stress-relieved specimens were of the same plate as used in the other tests. The as-welded, quenched and tempered specimens and the welded and stress relieved, quenched and tempered specimens were made from plate from a second commercial melt, Heat B. Temperature-impact curves for the two steels, quenched and tempered at 1150° F in 1-in. thick plate, are shown in Fig. 9. The two curves, although not identical, are similar and the values at the three selected temperatures are quite close. Consequently for comparative purposes, one steel can be substituted for the other without introducing a significant variable. Unfortunately, there was not sufficient plate from either heat to make Kinzel tests on the unwelded plate.

Results of the slow-bend tests for each of the four welded conditions are plotted in Fig. 10. The transition temperature in this test is selected as the temperature at which a lateral contraction of 1% is obtained across the width of the specimen at the fracture.

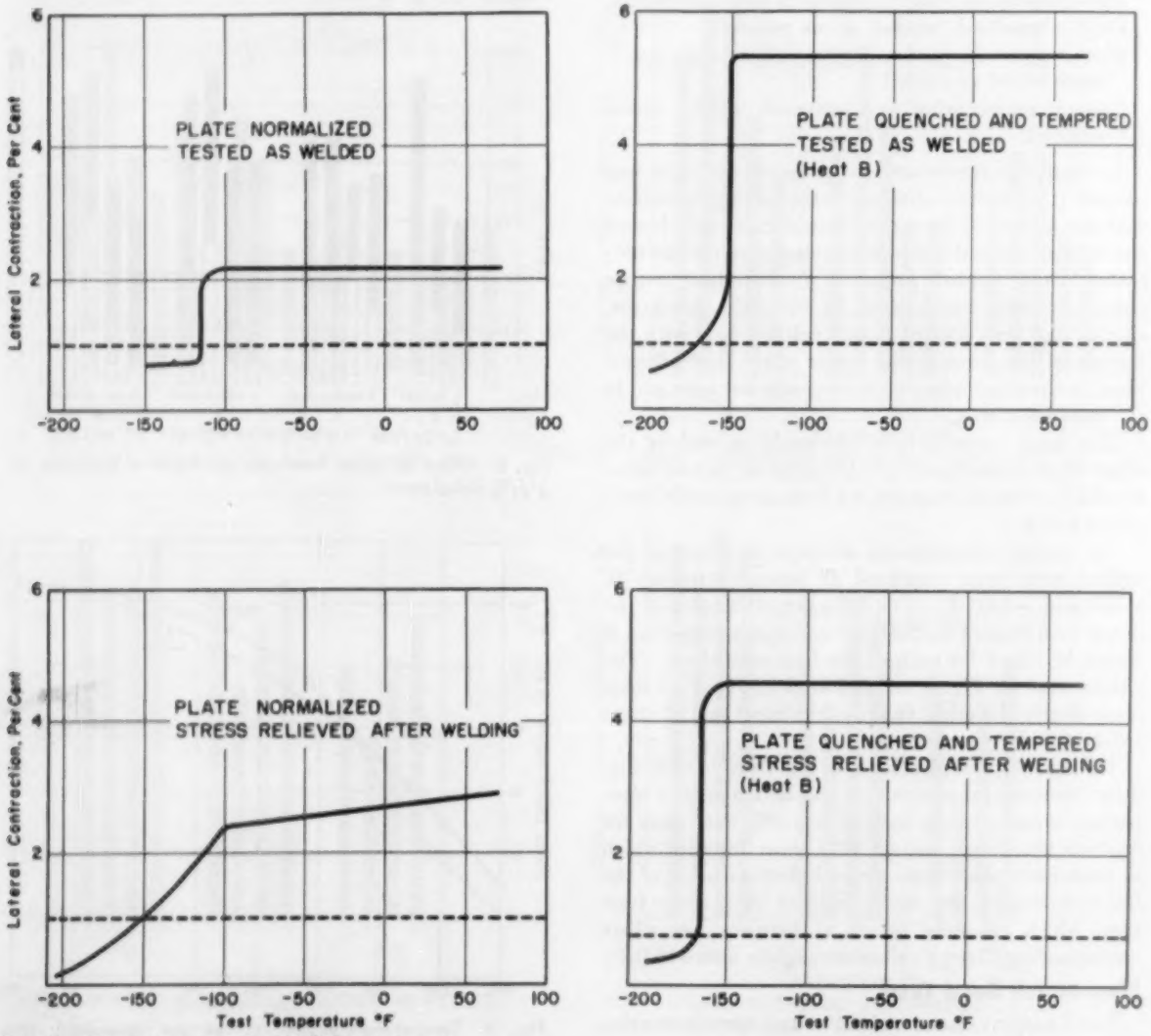

Fig. 10 Kinzel tests of welded 3½% nickel steel

Summary

Tempering or stress relieving slightly improves the Charpy impact (keyhole notch) properties of normalized 3½% nickel steel plate at 70, −100 and −150° F. Decidedly higher impact properties are obtained at all three test temperatures in quenched and tempered plate. Fracture appearance of broken Charpy specimens bears a direct relation to the Charpy values and may be used as the criterion for transition temperature (Figs. 1 and 2).

Charpy impact properties do not appear to be affected appreciably in 3½% nickel steel by increase in plate thickness from ½ to 1 in., but values for 2-in. thick plate are slightly lower than in 1-in. plate (Fig. 3).

Charpy impact properties at different locations in the welded area are not always as high as those in the unwelded plate. Lowest values usually occurred at the outer edge of the heat-affected zone and at the interface of the weld metal and the heat-affected zone. In no case was the Charpy value less than 15 ft-lb or ductile fracture less than 20% at temperatures down to −150° F (Figs. 7, 8 and 9).

Transition temperature in the slow-notch bend or Kinzel test was slightly below −100° F for the as-welded normalized plate, but for the other three conditions the transition temperature was −150° F or below (Fig. 10).

The results of this test indicate that welding does not appreciably lower the transition temperature of low-carbon, 3½% nickel steel plate, particularly if the welds are stress relieved.

Acknowledgment

The authors wish to acknowledge the assistance of the members of the staff at the Watertown Arsenal Research Laboratory who performed the tests, and of John Gross, Department of Metallurgy, Lehigh University, who made the Kinzel tests.

The statements and opinions appearing in this paper are those of the authors and do not necessarily reflect the views of the Army Ordnance Department.

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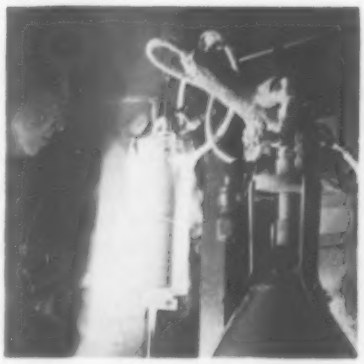
RESEARCH NEWS

New Metals Testing Chamber Operated at −452° F

Metallurgists at the Research Laboratories of Westinghouse Electric Corp. are conducting tensile tests on metals at temperatures as low as −452° F. The metal specimens are stressed within a specially designed chamber which has been cooled with liquid helium. Results of these tests will provide engineers with needed information regarding types of metals that are best suited for use under extreme temperature ranges. Information of this sort may well be useful in the design and development of guided missiles and future supersonic aircraft.

Although much larger testing apparatus has been used in low temperature experiments in the past, the Westinghouse-developed chamber, which is only slightly larger than a hand fire extinguisher, is believed to be the first of its kind to use liquid helium in order to attain the −452 deg mark for purposes of tension testing. Prior to use of liquid helium as refrigerant, tests were conducted at temperatures as low



as −320° Fahrenheit using liquid nitrogen.

The aims of these ultra subzero investigations are concerned with obtaining a better understanding of the strength of metals and the factors that cause embrittlement failures. For example, normal grades of steel become brittle and rubber loses its elasticity when subjected to these extremely low temperatures.

In operating this cold test chamber, a sample of the metal to be tested, about 1 in. long and ¼ in. diam, is placed inside the special vacuum insulated chamber. The sample is held securely at each end in special chucks. Liquid nitrogen is used for initial cooling of the chamber from room temperature to −320°. At this point liquid helium is introduced to take the temperature down to −452°.

Nitrogen is used in the room temperature to −320-deg range because it is considerably more economical and efficient than is the use of helium at these temperatures. Using these two refrigerants, tests can be conducted at any temperature from 0 to −452° F.

When chamber and test sample are stabilized at the desired temperature, a tension load is applied to the sample and is gradually increased until the piece of metal breaks. During the test the temperature of the metal specimen and also the stress-strain readings from the sample are recorded electrically on graphic charts. In current experiments, the maximum stress that can be applied to the ¼ in. diam sample is 260,000 psi.

(*Continued on page 240-s*)

EFFECTS OF RESIDUAL STRESSES IN WELDED STRUCTURES

BY G. M. BOYD

SYNOPSIS. The evidence for the effects of residual stresses arising from welding on the behavior of mild-steel structures is reviewed under the headings of tensile strength, fatigue, stress corrosion, brittle fracture, elastic stability, reaction stresses and weld cracking. It does not appear that residual stresses have any significant harmful effect. It seems probable that the detrimental effects generally attributed to residual stresses are in fact due to metallurgical changes, which in the presence of stresses may lead to fracture, and that the beneficial effects of stress relieving are due to the improvement of metallurgical structure.

Introduction

For many years, there has been widespread and inconclusive controversy on the influence of residual stresses on the behavior of welded structures under service conditions, particularly after the occurrence of some serious fractures in wartime-built ships and other structures. A number of research programs have been undertaken in several countries on the clarification of the stress behavior, but the knowledge obtained and opinions expressed on the matter are still confused.

The literature on the subject is very extensive, and no attempt at a complete review is made in this paper. The review is confined to ordinary mild-steel structures, and detailed references are kept to a minimum.

Definition of Residual Stresses

Residual stresses, for the purpose of this paper, are defined as those stresses which would exist within a structure* if all the stresses due to external loads were removed, including those due to the weight of the structure. Residual stresses are therefore balanced within the structure itself, and are independent of the external loads and reactions, although the application and removal of such external forces may in some circumstances modify the distribution of residual stresses. Examples of such stresses are the tensions in bolts or rivets, which are balanced by compressions in the adjacent material. Similarly, the differential cooling of rolled material and of material in the vicinity of welds causes plastic deformations which are accompanied by residual stress systems. This paper is concerned only with the residual stress systems that arise directly as a result of the use of welding.

The metallurgical transformations that occur within the metal during solidification and recrystallization produce residual stress systems which are self-balancing within small volumes of the order of the grain size. Such "tessellated" residual stress systems will not be considered here, since they occur even in the absence of welding.

Typical Residual Stress Patterns

The stress systems which arise from welding in complex structures are, of course, complex, but for the purposes of this discussion it will be sufficient to consider, in the first place, the stress patterns which arise in a simple butt weld between two flat plates. In this case there is a high tensile stress at the weld in the direction of the weld axis, i.e., in the longitudinal direction, balanced by longitudinal compressions in the plates remote from the weld (Figs. 1 and 5). These longitudinal stresses must be zero at the ends of the plates, and the maximum values are developed only at some distance from the ends, as shown by the dotted curves in Fig. 1. The maximum tension, along the center of the weld, approximates to the yield point of the weld metal; the maximum compression, along the edges of the plates, is comparatively low and its actual value depends on the width of the plates. The greater the width, the smaller is the compressive stress required to balance the tension in the weld. The extent of the tension zone, embracing the weld, is quite narrow, and of the order of the plate thickness.

Provided that the edges are free, the stresses transverse to the direction of the weld are small compared with those in the longitudinal direction, and are made up by tensions across the weld in the middle of the length, balanced by compressions across the weld at its ends. If the edges of the plates are restrained, either by increasing the width of the plate or by connecting the edges to rigid structures, the transverse stresses are increased. The additional stresses due to such restraints are usually termed reaction stresses.

The stress systems briefly described here are usually complicated by bending effects which result in increased stresses on one surface, balanced by reduced stresses on the other. Owing to these bending effects, which are usually present even when there is little visible distortion, the stresses are not uniform through the thickness of the plates.

Before considering the effects of residual stresses, it is desirable to observe the following property of such internally balanced stress systems generally. Consider the stress-strain relationship for any given point in a structure (Fig. 2). To produce a given residual stress S the material must be subjected to a certain strain ϵ_1

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* "Structure" in this context means any piece, or assemblage of pieces, of mild steel designed to transmit loads.

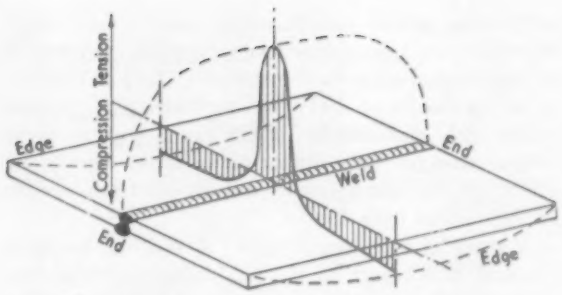

Fig. 1 Longitudinal stresses in a butt weld

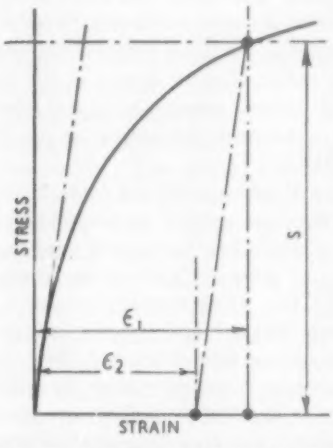

Fig. 2 Stress-strain relationship for a point within an internally balanced stress system

which exceeds the elastic limit, but in order completely to relieve the stress, only a very small relaxation is required, which is achieved by reducing the strain to a lower value ϵ_2 such that $\epsilon_1 - \epsilon_2 = S/E$, where E is the modulus of elasticity. Thus, to relieve a residual stress of 17 tons/sq in., a relaxation strain of only about 0.13% would be required. Fracture could therefore occur only if the material were incapable of withstanding a further plastic strain of this small amount. Such a material would be considered brittle.

A further property of the residual stress system in the longitudinal direction, i.e., parallel with the weld, is that a transverse fracture, if it occurs, can only relax the stresses over a short distance along the weld. To relieve the stresses along the whole length of the weld, therefore, a large number of short transverse fractures would be required, unless the stresses could be relieved by other means such as stretching or heat treatment. The length of such fractures is determined by the width of the tension zone which, as mentioned above, is quite narrow.

Effects of Residual Stresses

The available evidence on the effects of residual stresses on the behavior of welded structures will be reviewed under seven headings, as follows:

1. Tensile strength
2. Fatigue
3. Stress corrosion
4. Brittle fracture
5. Elastic stability
6. Reaction stresses
7. Weld cracking

Tensile Strength

Many investigations have been made on this aspect, and only the following need to be mentioned here.

Norton and Rosenthal[1] produced controlled residual stresses by local heating in flat-bar specimens, which were later tested in tension. It was found that local plastic flow occurred in the heated region at loads below the yield point of the virgin material. The residual stresses were relieved by tension at the level of the yield point of the virgin material, and after this the specimens behaved as if there were no residual stress. Further tests in static bending confirmed these results.

Patton and others[2] made extensive tests on welded girders in Russia, and found that the residual stresses were relieved by local plastic flow under yield-point loads. These workers concluded that: "The safety of the structure will not be obstructed, even if the sum of the working and shrinkage stresses is greater than the allowable stress." They observed local deformations at low loads, but considered that these did not impair the safety.

Jamieson[3] made tensile tests on specimens with welds in U grooves along the edges, and on plain unwelded specimens. He found that the welding reduced the breaking stress by about 9% and reduced the elongation from 33 to 12%. The fractures started at the welded edges, and this was attributed to irregularities or flaws. After loading above the yield point of the parent plate, the welded specimens behaved, on reloading, in the same way as unwelded specimens.

Wilson and Hao[4] made an extensive series of tensile tests on wide plate specimens with and without longitudinal welded joints, and found that:

1. Compared with the unwelded specimen, the welded specimens showed greater deformation below the yield point, and less above it. The welded specimens showed higher yield points, slightly lower maximum loads, lower elongations, and lower reductions of area.
2. Strips containing the welds, cut from wide specimens, showed significantly lower elongations at fracture.
3. The residual stress was greatly reduced by loading a welded specimen beyond the yield point and then unloading, but this did not appreciably affect the strength or ductility.
4. In tests on specimens 40 in. wide by $^3/_4$ in. thick, longitudinal welds had no significant effect on strength whether made manually or automatically, and whether low-temperature stress relieved or not.
5. The elongations of untreated welded specimens were about 90% of those of unwelded specimens. Low-temperature stress relieving slightly reduced the elongations.

6. In general, the fractures started from the welds. This was attributed to lower ductility of the weld metal.

7. Specimens with circular welds failed outside the welded region, at slightly increased loads.

8. One of the specimens fractured in a brittle manner, but in this case the fracture started at the edge of the specimen, not at the weld.

Bibber[5] made extensive tensile tests on heavy sections incorporating welds and concluded that:

1. At extreme elongations the welds cracked at intervals "to accommodate themselves to the greater ductility of the plate."

2. Stress-relief annealing (no details given) considerably increased the elongation.

3. Joints with transverse residual tensions developed slightly less over-all strength and elongation than those containing primarily longitudinal stresses.

Fatigue

Many experiments have been made to determine the effects of residual stresses on fatigue strength without conclusive results, partly owing to the inherent scatter in fatigue tests, and partly because of the presence of many confusing variables which could not be eliminated without also eliminating the residual stresses. A further difficulty seems to have been the high cost of the many large specimens required.

Wilson and Hao[4] made a series of push-pull tests on specimens of 5- x $^{7}/_{8}$-in. section having longitudinal welded joints in several conditions, viz., as-welded, with welds planed and draw-filed smooth, and stress relieved by stretching above the yield point. Unwelded control specimens were also tested. The usual scatter of results was found, and it was concluded that "welded plates with high residual stress had a slightly lower fatigue strength than similar plates stress relieved by stretching, but the difference did not exceed the scatter of the various tests."

A group of members of the U. S. Welding Research Council, in a report on the weld stress problem[6] concluded: "A comprehensive series of fatigue tests on large-size welded coupons, and extending over several years, indicates that under full alternating stress the endurance limit of unstress-relieved coupons is substantially the same as for stress-relieved coupons."

In a very comprehensive survey of the literature on the effects of residual stresses, Stitt and Chadsey[7] state that "Any unrelieved residual stress has little or no effect on fatigue."

Harris and Weck[8] carried out fatigue tests in bending by the resonant method on six mild-steel shafts of 4 in. diam, of which four had a weld bead deposited in a circumferential groove. Two of the shafts were annealed at 650° C. These workers concluded that the six tests indicate that residual stresses may decrease the fatigue strength of mild steel, but they also indicate that this decrease is not very large, and may easily be masked by the effect of weld flaws or other incidental discontinuities. The annealing treatment resulted in a

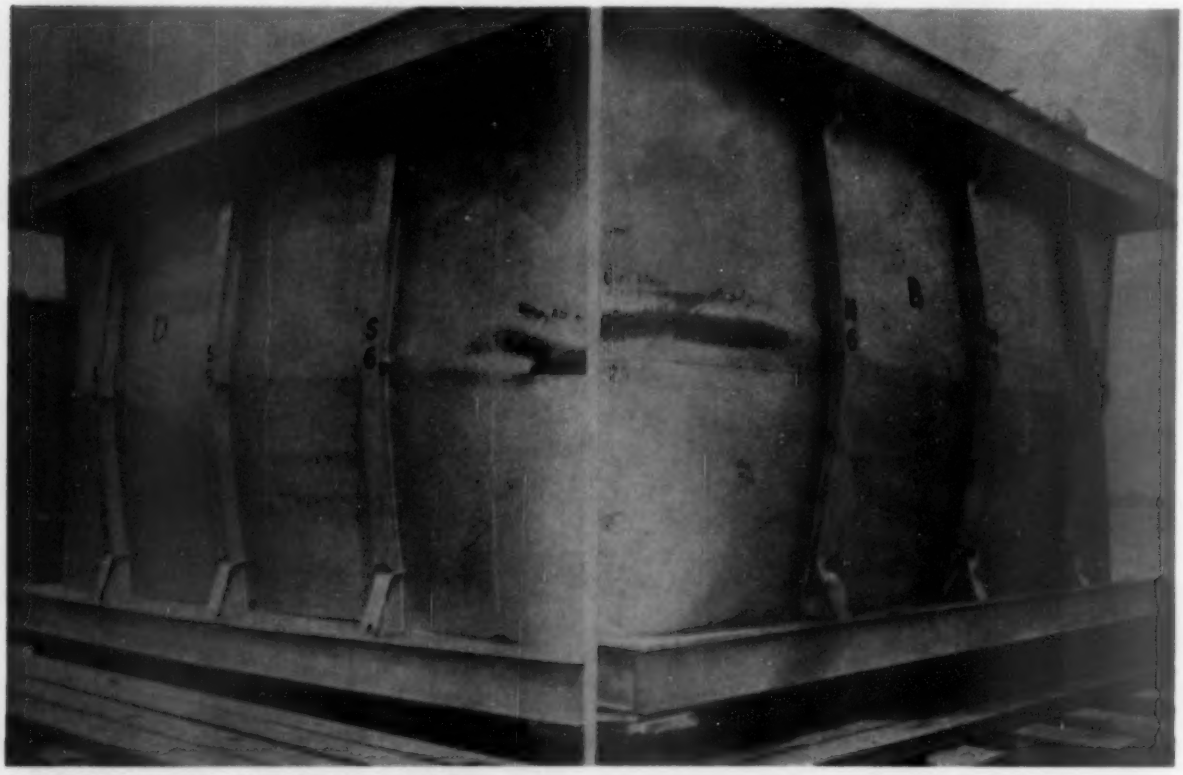

Fig. 3 Welded tank subjected to shock loading.

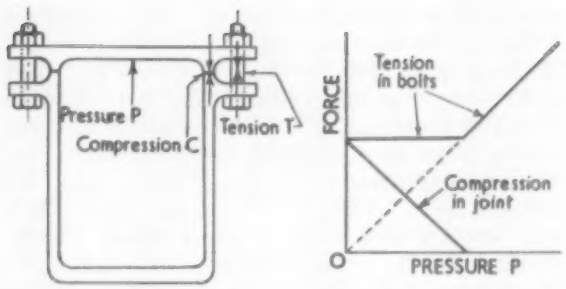

Fig. 4 Relation of stresses present in cylinder with bolted cover

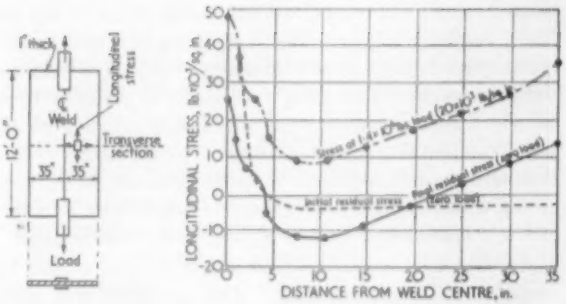

Fig. 5 Redistribution of residual stresses for a submerged-arc weld when loaded in direction of weld and then relaxed

slight improvement, but did not restore the fatigue life to that of the unrelieved specimens.

In the investigation of the effects of residual stresses on fatigue strength, it is necessary to compare identical welded specimens in the as-welded and stress-relieved conditions. It is impossible, however, to ensure that the stress relieving does not produce other effects, besides removing the stresses. The comparison therefore reduces to a study of the effects on fatigue strength of particular treatments, such as annealing at 650° C., stretching, etc. The effects on fatigue strength of the particular heat treatment known as stress relieving were discussed by Weck in an unpublished report.[9] This cited the work of several investigators which showed that this heat treatment sometimes slightly improved the fatigue strength, sometimes slightly reduced it and in other cases had no significant effect.

Stress Corrosion

Whereas a good deal of work has been done on the effect of externally applied stress on the incidence of stress-corrosion cracking, very little consideration has been given to the effect of residual stress in this connection. The effect of residual stress combined with the presence of certain chemicals in producing rapid failure by cracking is well known, for instance, in the α brasses and bronzes. Similar cracking can be induced in mild steel in contact with a number of chemicals, but there does not appear to be any recorded case of failure of this type on mild-steel structures (e.g., ships, dock gates, bridges) in contact with sea water or with the atmosphere.

Examples of cracking of stressed mild steel in contact with caustic alkalies, inorganic nitrates, nitric acid and other chemicals are well known. While it is known that similar cracking can develop in welded mild steel in contact with these chemicals, it has not been proved that the cracking results from residual stresses due to welding, rather than to some other effect of welding such as the metallurgical changes resulting from the welding heat. Clearly, some further systematic investigation of this matter would be desirable.

Brittle Fracture

The problem of brittle fracture in ductile materials, such as mild steel, is very complex and, as yet, imperfectly understood. It is natural, therefore, that the effects of residual stresses on the incidence of this phenomenon are not very clear.

Brittle fractures which have occurred in ships have been extensively investigated in America under the auspices of the U. S. Board of Investigation and the U. S. Ship Structure Committee, and in the United Kingdom by the Admiralty Ship Welding Committee. These investigators independently concluded that the residual stresses arising from welding were not an important factor in causing the fractures. The conclusions were variously worded, but have been summarized[10] as follows:

"Regardless of procedure, sequence of welding or restraint, every welded structure (unless stress relieved) contains locked-up stresses which locally reach the yield point of the material. Continued researches have so far not revealed evidence that these locked-up stresses have adverse effects on the strength and reliability of welded ships' structures, provided that the material, including the weld, is in a notch-tough condition at the prevailing temperature."

It is clear from this that the Committee, in agreement with other investigators, believes that residual stresses cannot cause brittle fracture in a ductile material, but if the material is in a notch-brittle condition residual stresses can produce brittle fracture in the same way as other stresses, provided that a suitable notch is present.

Kennedy[11] demonstrated "spontaneous" fracture without the application of external load in the following manner. A rectangular opening was cut in the middle of a heavy steel slab, and a steel specimen containing an internal notch was welded into the opening under the severe restraint afforded by the slab. The specimen was then cooled with solid carbon dioxide, and after some delay a brittle fracture originating from the notch occurred suddenly. In this experiment the cooling had two effects: the stress was increased owing to the temperature difference between the specimen and the frame, and at the same time the specimen was "embrittled" by the fall in temperature. It could not be said, therefore, that the fracture was entirely due to the residual stress.

To settle this point, Kennedy's experiment was re-

operating against the rigidity of the surrounding struc-

is difficult to avoid when welding is carried out "under

peated under controlled conditions by Weck,[12] but in this case the whole assembly, i.e., frame and specimens, was cooled evenly, so as to eliminate thermal stresses as far as possible. Five tests were made, in the first three of which the specimens were of ordinary coarse-grained mild steel having a high transition temperature. The remaining two specimens were fine-grained steels, one being a normalized low-carbon Al-killed steel, and the other a normalized Cr-Mo high-tensile weldable steel.

In test 1, a coarse-grained specimen was cooled to −60° C without cracking. The specimen was then warmed, and a heavy stiffener was welded on, straddling the notch. On recooling (Test 2), a brittle fracture occurred at −9° C, at which temperature the Izod impact value was about 12 ft-lb. In Test 3, also on coarse-grained steel with a stiffener, a brittle fracture occurred at −7° C. In Tests 4 and 5, on the fine-grained specimens of Al-killed and Cr-Mo steel, respectively, no fracture occurred, although the specimens were cooled to −65° C and −69° C, respectively, and hammered while at these temperatures.

In all these tests the residual stresses and notch effects were undoubtedly severe, and the temperatures reached were well below the transition ranges as indicated by Izod tests. It can therefore be concluded that in this series of experiments severe residual stresses, in the presence of a severe notch, were unable to produce brittle fracture except when the material was a coarse-grained mild steel having a high transition temperature.

Anderson and Waggoner[13] made tensile tests on specimens of 10- x 1/4-in. section in three conditions: (*a*) as-rolled without welds, (*b*) with various weld-bead patterns criss-crossing the faces of the specimens, (*c*) normalized after welding with various weld patterns. The tests were made at two temperatures, viz., 75° F (24° C) and −80° F (−62° C).

It was found that normalizing had little effect on the yield point or ultimate stress at either temperature. It did, however, considerably increase the reduction of area in the tests at low temperature. At the lower temperature the normalized specimens broke with shear fractures, whereas the unnormalized specimens were brittle. Welding had little effect on the yield point or ultimate strength of either the normalized or unnormalized specimens, but it produced a marked fall in the reduction of area of both. There was no significant difference in behavior between the specimens welded in different patterns.

It may be concluded from these experiments that the welds behaved in the same way as notches, reducing the ductility at the low temperature, but having little effect at the high temperature. Normalizing apparently increased the ductility at the low temperature, an effect which is frequently observed with notched specimens which are not welded. None of the effects observed by Anderson and Waggoner can be attributed solely to residual stresses.

That welding is not by itself a cause of brittleness is shown by the ductile behavior of many welded structures under static and shock loading. Pierce[14] describes a large experimental open-top tank, welded by normal shipbuilding methods, in which explosives were fired under water, causing severe bulging but no leaks (Fig. 3). Many cases are on record of welded ships sustaining severe damage through under-water explosions without brittle fracture occurring except when the temperature was near 0° C. In the case of one welded ship which grounded, where severe bottom damage occurred and the plates folded concertina fashion, all the fractures were ductile. The same ship, about a year later, broke in two in a brittle manner when the temperature was about 20° C lower than at the time of the previous grounding.

Offord[15] tested hollow welded drums submitted to underwater explosions, and found that the fractures were sometimes ductile and sometimes brittle, irrespective of whether the specimens were normalized or not. Offord concluded that no increase resulted in the charge required to rupture, and no change was obtained in the type of fracture, if the plates were normalized at 900° C before use and/or heat treated to 650° C after welding, to relieve locked-up stresses. More recent analyses of the results, however, are said to indicate some benefit from heat treatment.

Elastic Stability

Little experimental work seems to have been done to evaluate the effects of residual stresses on the elastic stability of slender structures, although welded slender tubes subjected to compression have been found to fail at lower loads than were expected, and this has been attributed to residual stresses.

Logically, it would appear that in such tubes a longitudinal weld would produce unsymmetrical residual stresses, the effect of which should be equivalent to eccentricity of loading. This does not, however, seem to have been verified by controlled experiments.

On the other hand, tests were made at the University of Illinois[16] on slender struts (length-radius of gyration 64-75) for railway viaducts, having welded reinforcement, and the tests indicated that: "Although there were residual stresses in the columns of 30,000 lb/sq in. before the columns were loaded, the addition of the reinforcing plates increased the load-carrying capacity in direct proportion to the increase in section, that is, the reinforcing plates were 100% effective in increasing the load-carrying capacity of the columns, even though residual stresses of 30,000 lb/sq in. were induced by the welding process." The reinforcements were presumably placed symmetrically with respect to the axes of the columns, otherwise eccentricity would probably have arisen because of distortion. This, however, should be distinguished from the presence of residual stress.

Reaction Stresses

Reaction stresses differ from the residual stresses previously discussed in that they are balanced within the structure on a larger scale. If an insert plate is welded into an opening in a structure, stresses are developed owing to the contractions of the closing welds,

operating against the rigidity of the surrounding structure and of the insert itself. It is often thought that, whereas the "ordinary" residual stresses may be unimportant, "reaction" stresses may build up to dangerous proportions, particularly in rigid structures.

This possibility was investigated in a series of experiments by Weck.[17] In the preliminary stages of this work, narrow strip specimens were welded in a stiff restraining frame, by a variety of procedures. The resulting reaction stresses were much lower than anticipated, i.e., less than 3 tons/sq in. A second series of experiments was therefore carried out in a restraining frame of very much greater rigidity, and reaction stresses up to about 13 tons/sq in. were obtained. Although the restraints were considerably greater than are likely to occur in a normal structure, no fractures occurred. A further series of tests was carried out, using wide plate specimens (two 60- x 30-in. plates welded together to form a 60-in. square) heavily restrained in both directions by attachment to a concrete slab. The resulting reaction stresses were again low, amounting to only about 2.5 tons/sq in.

During the experiment with the rigid steel frame, three specimens were cooled with solid carbon dioxide to about −40° C. Reaction stresses of 15–16 tons/sq in., already in these specimens, were increased by cooling to about 20 tons/sq in., i.e., well above the yield point. No fractures occurred even though the temperature was well below the transition range of the specimens as determined by notched tensile tests. When the specimens were warmed to room temperature the original reaction stresses had diminished by about 3 tons/sq in. From these experiments it was concluded that: "Plastic flow and relief of reaction stresses will take place in mild-steel structures, in consequence of differential heating and cooling, even at temperatures far below the transition temperature. Moreover, the combined action of residual stresses and reaction stresses will not result in spontaneous brittle fracture, even at temperatures below the transition temperature, provided that notches are absent."

It is apparent from these experiments and those cited earlier that, to produce brittle fractures under the action of residual and reaction stresses, two conditions must be fulfilled: the temperature must be below the transition range of the material, and there must be a notch at a suitable position. These conditions are necessary, but not always sufficient.

It may be conjectured that reaction stresses may have some effect on fatigue strength, since they may have the effect of locally increasing the mean stress produced by fluctuating external loads. Similarly, in some circumstances reaction stresses possibly reduce the critical loads for local elastic instability. However, there is no experimental evidence to support these conjectures, nor can any reliable record be found of their confirmation by failures in service.

Weld Cracking

It is well known that cracking of welds, with occasional propagation of such cracks into the parent metal, is difficult to avoid when welding is carried out "under restraint." It may be remarked that all arc welding must be subject to some restraint, since the solidified metal in the wake of the arc must oppose the contraction of the newly deposited metal.

Recent research by the BWRA, particularly the work of Cottrell,[18, 19] has clearly shown that weld cracking is due to brittleness of the metal, induced either by passage through a "brittle" range during cooling, or by the presence of hydrogen in either the weld metal or in the parent material. The same work has shown that the tendency to cracking is little affected by the mechanical restraint but is strongly affected by the rate of cooling, high cooling rates favoring cracking. The rate of cooling is, however, increased by many of the factors which increase restraint, such as thickness and the welding of small inserts into large structures. This probably explains the belief that the restraint is the cause of the cracking. In the light of this experimental work, however, it appears more rational to attribute the cracking to local, and often temporary, brittleness.

Cottrell's work has also shown that cracking is a time-dependent phenomenon, which explains the occurrence of weld cracking some time after the weld has cooled. Such delayed cracking, which has been shown to be closely related to the presence of hydrogen, may result in fracture of the parent material, if this happens to be below its transition temperature.

The remedy for such cracking, therefore, seems to lie not in the removal of the stresses, but in measures to control the cooling rate, such as preheating and the use of heavy runs, and in the control of hydrogen in the electrodes and parent metal.

Discussion

There is little or no evidence that the residual and reaction stresses produced by welding are in any way harmful. This conclusion is difficult to accept, for it appears that if stresses up to the yield point exist in a structure before the external loads are applied, the resulting combined stresses must at some points be additive and must therefore reach dangerous proportions. In fact, however, the picture is not so simple as it might appear on this reasoning.

In the first place, the superimposition of external loads on an internally balanced initial stress system is not a matter of simple addition. Consider the arrangement shown diagrammatically in Fig. 4, i.e., a cylinder with bolted cover. Before the pressure is applied, the bolts are in tension, and this is balanced by the compression in the joints. As the pressure is increased from zero, the compression in the joint decreases, with a consequent reduction in the bolt tension required to balance it. This reduction in the tension is, however, counteracted by the pressure, so that the actual tension in the bolts remains constant up to the point at which the compression becomes zero. Thereafter, the tension in the bolts increases in proportion to the pressure, if there is no leakage. The tension in the bolts is therefore not simply the sum of the initial tension and that due to the pressure. This is of course an oversimplified picture,

shown by the ductile behavior of many welded structures, since the deformations have been ignored, but it may serve to illustrate the point.

A further reason for the fact that the superimposition of stresses is not a simple addition is the occurrence of plastic flow. This has been demonstrated by Meriam, DeGarmo and Jonassen,[20] and is illustrated in Fig. 5. The stress distributions before, during and after loading are shown, and it can be seen that the stress at the weld was not increased by the superimposed stress of 20,000 psi. This effect was, of course, due to local yielding, which always occurs in such circumstances, provided that the material is ductile and free from cracks. When the load was released, the stress remaining at the weld was found to have diminished by the amount of the applied stress. Further loading and unloading within the range of the first application of stress would not cause further plastic flow.

Nevertheless, it is known that in general, stress relieving is beneficial; it is, in fact, required by many specifications. It is not known, however, whether the benefit is in fact due to the elimination of residual stresses or to other effects, and it is suggested that it is due to metallurgical effects. This was also the conclusion reached by the Weld Stress Committee of the American Welding Research Council, and is embodied in their final report[21] as follows:

"Stress-relieving treatments, particularly thermal, have been proved to be beneficial in so far as the quality of a welded joint is concerned, and are still considered a necessity in many structures, as, for example, pressure vessels, machinery parts and the like. The beneficial effects are not primarily due to the reduction of residual stresses but rather to improvement of metallurgical structure, dimensional stability in machining operations and reductions in stress-corrosion potentialities."

It is beyond question that undesirable metallurgical effects may, and usually do, arise in the vicinity of welds. These result from the temperature cycles, which involve melting, solidification and allotropic transformations, and also from plastic flow at various temperatures, including "cold working" at some distance from the weld. Moreover, as noted earlier, hydrogen and possibly other detrimental nonmetallics may be introduced. In addition, it is known that strain aging and quench aging occur in steels subject to these phenomena, and these are known to have a pronounced embrittling effect.

The heat treatment known as stress relieving, i.e., heating to about 650° C followed by slow cooling, is beneficial in removing some of these detrimental effects in some types of mild steel. That this particular form of heat treatment may not always be fully effective has been shown by some recent work under the American Ship Structure Committee.[22]

Other forms of stress-relieving, such as mechanical stretching, which include the process known as low-temperature stress-relief, whilst reducing the stresses, probably aggravate the metallurgical effects cited.

Conclusions

1. No evidence has been found that the residual or reaction stresses which arise from arc welding have any significant detrimental effect on the strength or endurance of mild-steel structures, except possibly where stress corrosion or elastic instability are involved.

2. It seems probable that the detrimental effects usually attributed to residual and reaction stresses are in fact due to metallurgical changes, which in the presence of stresses may lead to fracture.

3. The beneficial effects of the heat treatment known as stress relieving are probably due, not to the reduction of stress, but to improvement in the metallurgical structure.

4. Mechanical stress relieving, by stretching, may be effective in removing or reducing the stresses, but probably aggravates the adverse metallurgical effect of welding.

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FURTHER STUDIES OF THE FLASH WELDING OF STEELS

Cooling rate of AISI 1020 and 4340 steels are the same if specimen geometry, platen acceleration and clamping distance are maintained the same

BY E. F. NIPPES, W. F. SAVAGE, G. GROTKE AND S. M. ROBELOTTO

ABSTRACT. Weld centerline rates of cooling at 1300, 1000 and 900° F in flash welds in AISI 1020 and 4340 steels, prepared under similar conditions, were measured and compared. The cooling rate is not influenced by the composition of the steel if the specimen geometry, platen acceleration and final clamping distance are maintained constant. Weld zone cooling rates were determined for welds in AISI 1020 steel subjected to 1.5 sec of upset current at an average current density of 18,500 amp/in.^{2}. The reduction in cooling rate produced by this upset current flow was obtained by comparison with previous data on welds without post-upset current. The temperature distribution in the vicinity of the weld zone was measured experimentally during the application of 4.75 sec of temper current at an average density of 21,400 amp/in.^{2}. Three steels of differing elevated-temperature strength were employed for welds prepared at four rates of platen acceleration to determine the influence of the composition of the steel and the influence of the temperature gradient, established during flashing, on the upset force requirements.

Introduction

Perhaps no welding process requires the proper proportioning of as many variables for the production of a satisfactory weld as does flash welding. The over-all flash welding process may be conveniently divided into two major portions: (1) The flashing portion and (2) the upset portion.

Flashing

During the flashing portion, the ends of the pieces to be welded are prepared for the upsetting action by producing a layer of molten material on the interface, and establishing a suitable temperature gradient in the piece to reduce the compressive yield strength of the material in order to facilitate upsetting. Previous research [1,2] in these laboratories has added to the understanding of the influence of the flashing variables on the temperature distribution, demonstrated the superiority of a constant rate of platen acceleration in creating a stable temperature gradient, as compared with constant velocity platen movement, and indicated a method of selecting flashing variables to produce a desired temperature distribution. Additional research[3] at Rensselaer has contributed to the understanding of the interrelation between flashing and upset variables.

Upset

During the upset portion, the workpieces are rapidly accelerated toward one another under the action of a large upset force, causing the molten layer produced on the flashing interfaces to be violently expelled, and forging the underlying, hot, plastic material together to form a sound recrystallization-type bond between the workpieces. Since during the latter portion of flashing the entire flashing interface is covered by a layer of molten metal, all oxides and nitrides formed by contact with the atmosphere tend to be trapped in this molten layer, and are effectively removed by the expulsion of the molten layer during the initial instant of upset. The underlying material, thus fluxed by the molten metal, and rendered plastic by the temperature gradient established during flashing, is then in a suitable condition for the forging action which occurs during upset.

A third program of investigation recently completed[3] in these laboratories summarized the influence of flashing the upset variables on the weld cooling rates, and presented typical photomicrographs of weld microstructures together with performance data. By correlating the temperature distribution during upset, the weld cooling rates and the published data on the hardenability of the steels involved, it was possible to predict the weld hardness with a reasonable degree of accuracy.

However, during the course of previous investigations numerous questions remained unanswered. For example:

1. What is the effect of upset current in reducing the weld cooling rates, and therefore the weld hardness?
2. What is the effect of the composition of the steel on the cooling rates during upset?
3. Is machine tempering a practical means of reducing the weld hardness?
4. What is the effect of the temperature distribution at the instant of upset on the upset force requirements?

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Table 1—Composition of the Steels Employed for Weld Specimens

Steel	Heat No.	% C	P	S	Si	Mn	Cr	Mo	Ni
AISI 1020	Nominal	0.18-0.23	0.04 max	0.05 max	..	0.30-0.60	..	..	..
AISI 4130	H34362A	0.295	0.014	0.018	0.25	0.53	0.95	0.21	..
AISI 4340	H34308A	0.385	0.013	0.022	0.23	0.78	0.80	0.25	1.74

The following report summarizes the investigations performed thus far in search of answers to the above questions.

Material

The steels used for this investigation are listed, together with their compositions, in Table 1. All material was hot rolled, and supplied in the pickled-and-oiled condition. The steels were degreased prior to use and excessive scale removed, where necessary, by abrasive-belt grinding. No special end preparation was utilized other than cutting to length on an abrasive cutting-off wheel, and removing the burr by a light grinding operation. Experimental data for this report were obtained from welds in $^{3}/_{8}$- x 2- x 6-in. rectangular specimens.

Equipment

Welding Equipment

This investigation was conducted using a Federal 300-kva flash welder modified in this laboratory as described in previous reports[4,5]. Power supply for welding was obtained from a single-phase alternator driven by a synchronous motor, as previously described.

Instrumentation

The data for this investigation were obtained using a Consolidated Engineering Corp. 18-channel recording oscillograph.

Object and Scope

The objects of this investigation were as follows:

1. To check experimentally the assumption that the composition of the steel has no significant effect on the temperature distributions and cooling rates encountered in flash welding.
2. To conduct a preliminary investigation of the effect of upset current in reducing the weld cooling rates during and after upset.
3. To conduct a preliminary investigation of tempering in the machine.
4. To determine the effects of temperature distribution and the composition of the steel on upset force requirements.

In the interest of clarity, this report has been divided into four parts, corresponding to the four objects presented above.

PART I EFFECT OF THE COMPOSITION OF THE STEEL EMPLOYED ON THE COOLING RATE IN FLASH WELDS

In a previous study of the cooling rates obtained in flash welds[3], in which the thermal data were obtained from welds made exclusively in plain-carbon steel, it was assumed that these cooling rate data would be equally applicable to welds employing alloyed steels. This assumption, though not experimentally investigated at the time, was supported by previous experience.

Although the electrical and thermal properties of most constructional steels are not significantly altered by changes in chemical composition[6], it was found that differences in composition could result in considerable variation in upset behavior. This would be expected in view of the marked effect of alloying additions in enhancing the elevated-temperature strength of steels. The difference in upsetting action due to differences in elevated-temperature strength introduced a complication in the application of the previously determined cooling rate data to alloy steels. For the purpose of the previous investigation it was decided to select equivalent welding conditions which would produce the same rate of cooling in welds in each of three steels of differing composition. These welds were then subjected to physical tests and examined metallographically. Since it was known that the final clamping distance was the most influential factor in determining the cooling rate, allowance was made by flashing off more of the less readily upset alloy steels in order to maintain the same final clamping distance. This increased flashing burn-off had no effect on the temperature distribution in the specimens at the moment of upset, since it had been shown previously[1] that once the stable temperature distribution has been established, further flashing action produces no change in the temperature gradient.

Thus, no complication arose from the fact that the burn-off was increased. However, the reduction in upset travel introduced the possibility that similar cooling conditions might not have been obtained even though the final clamping distances were the same. The possible effect of the reduction in upset distance encountered in alloy steels was thought to depend on two factors which were essentially self-compensating.

1. With the less readily upset alloy steels, the reduced volume of hot metal extruded as flash at the weld line would result in a slightly more rapid rate of cooling.
2. With the less readily upset alloy steels, the flashing action is continued longer so that prior to upset the temperature gradient is distorted in the vicinity of the welder jaws. At upset, the net effect of this distortion would be a slight reduction in the cooling rate.

Since, as far as the measured cooling rate was concerned, the effect of these two factors was not considered to be of large magnitude, and since they were to some extent self-compensating, it was assumed that the experimentally obtained cooling rate data for welds made in AISI 1020 steel were directly applicable to

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welds made in steels of other compositions.

An experimental check on the validity of this assumption was the first item for consideration in the present report.

Preparation of Specimens and Procedure for Obtaining Thermal Data

The experimental data for comparison of cooling rates were obtained using specimens of AISI 1020 and AISI 4340 steel of $^3/_8$- x 2- x 6-in. specimen size. The initial clamping distance was 1.5 in. for all welds, with platen acceleration constant at 0.04 ips^2. In all cases the current cut-off occurred exactly at upset. The burn-off was increased for welds made employing AISI 4340 steel so that a final clamping distance of 0.71 ± 0.01 in. could be maintained in both the plain-carbon and alloy grades. One specimen of each pair to be welded was drilled with 0.052-in. diam holes for the insertion of seven thermocouples. The holes were located at 0.1-in. intervals by use of a specially constructed jig, described in a previous report.[1] The thermocouples, made from 0.012-in. diam chromel-alumel-duplex wire, were welded securely to the bottom of the thermocouple holes after the specimens were placed in the welder jaws. A 220-mfd bank of capacitors, previously charged to 350 v, was discharged through the specimen-thermocouple contact in order to produce intimate bonding between the thermocouple hot junction and the bottom of the thermocouple hole. Thermocouples were located at distances approximately 0.3, 0.4, 0.5, 0.6, 0.7, 0.8 and 0.9 in. from the initial flashing interface and the exact location of each thermocouple was determined from radiographs of each specimen made before and after welding.

The output of the seven thermocouples was fed to a recording oscillograph and a continuous record of the temperature at each thermocouple location, the platen position and the force exerted at upset was obtained as a function of time. Oscillographic records were taken for the entire period from prior to the initiation of flashing until the weld had cooled to at least 200° F. Four duplicate runs were made in each steel and suitable records obtained in order to eliminate random errors.

After the flash was removed by abrasive-belt grinding, the weld centerline was located by etching with a 10% aqueous solution of nitric acid and a 0.01-in. diam wire was taped in place at the centerline. The weld was then radiographed and the thermocouple to weld-centerline distances were measured from the radiograph to the nearest 0.01 in.

Treatment of the Data

Figure 1 summarizes the temperature data obtained from a typical experimental flash weld. Each of the seven curves of this figure represents a plot of the temperature as a function of time after upset for one particular thermocouple location. Since four duplicate experimental runs were made employing both AISI

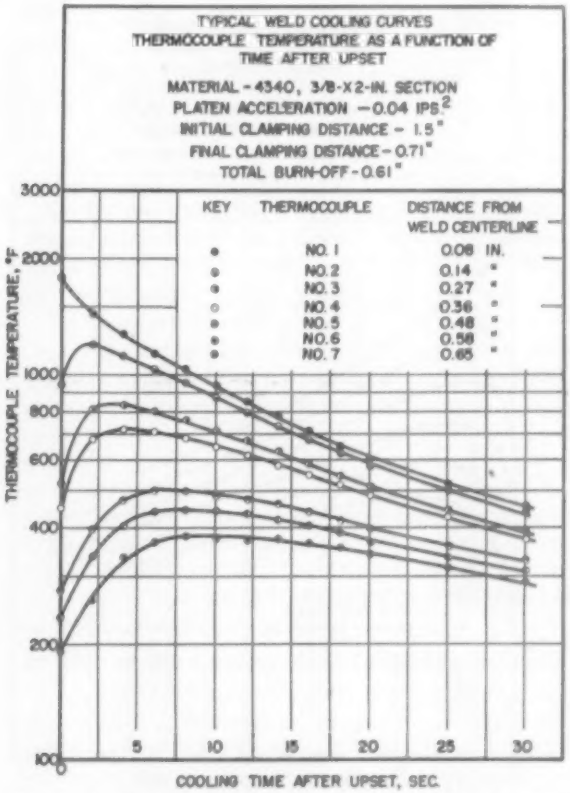

Fig. 1 Typical weld cooling curves—thermocouple temperature as a function of time after upset

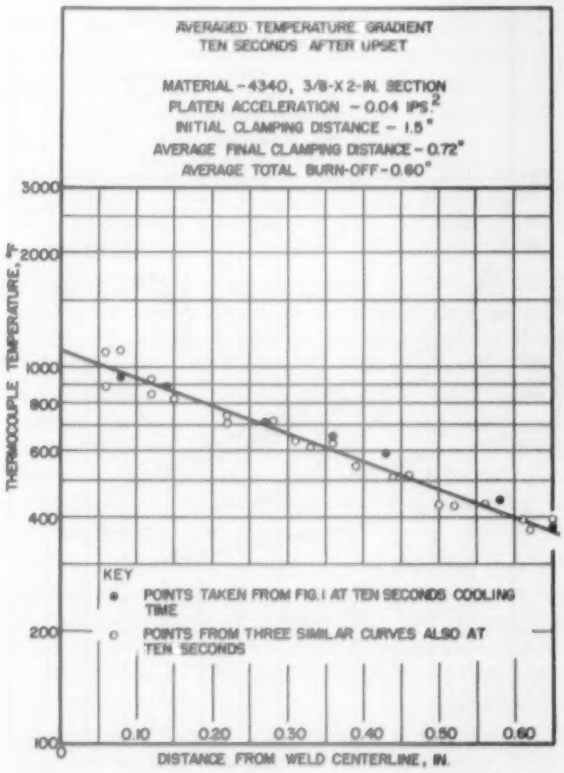

Fig. 2 Averaged temperature gradient ten seconds after upset

4340 and AISI 1020 steels, a total of eight plots similar to Fig. 1 were obtained. Because it was impossible to locate the thermocouples at exactly the same distances in all four specimens of a group, thermal data could not be directly compared in the form shown in Fig. 1. A further complication arose from the effect of the upsetting action on the locations of the hot junctions of thermocouples nearest to the flashing interface. For example, the radiographic determination of the location of the hot junctions would often indicate that after upset the first two or even three thermocouples were all located at approximately the same distance from the weld centerline. This was not the case, however, since these thermocouples would be indicating different temperatures, and therefore it was necessary to provide compensation for this effective change in hot junction location. This effect, of course, was much more pronounced in specimens of plain-carbon steel in which the upset travel was relatively greater, but is not particularly noticeable in the thermocouple locations, shown in the key to Fig. 1, for a weld in alloy steel. For these reasons it was necessary to subject the raw data to a normalizing process in order to obtain averaged data in a more usable form.

The first step in the normalizing process involved plotting temperature as a function of distance from the weld line for various instantaneous times after upset. Figure 2 is a typical example of the results obtained by this operation, and shows the temperature distribution in the specimen 10 sec after upset. Additional plots of a similar nature were also made for times of 0, 2, 4, 6, 8, 12, 14, 16, 18, 20, 25 and 30 sec after upset. The seven solid black points in Fig. 2 represent the instantaneous temperatures indicated in Fig. 1 by the seven thermocouples, 10 sec after upset. The open circles represent similar data obtained from the other three welds in the same steel and at the same welding conditions. Figure 2 shows how the average temperature gradient in the specimen may be readily established when all the instantaneous temperature data are plotted as the above method on a logarithmic scale.

The average temperature gradients existing in the specimens at times of 0, 2, 4, 6, 10, 20 and 30 sec after upset are indicated in Fig. 3. For greater clarity, the temperature gradients after 4, 8, 12, 14, 16, 18 and 25 sec of cooling have been omitted from this figure. Since the temperature gradient at zero time rises steeply at distances less than 0.1 in. from the weld line and since experimental difficulties did not permit exact determination of the temperature at the weld centerline at the instant of upset, the melting point of the material was arbitrarily chosen as representing the upper limit of possibility and the region of uncertainty has been indicated by the dashed portion of the curve.

After the temperature distribution at certain critical

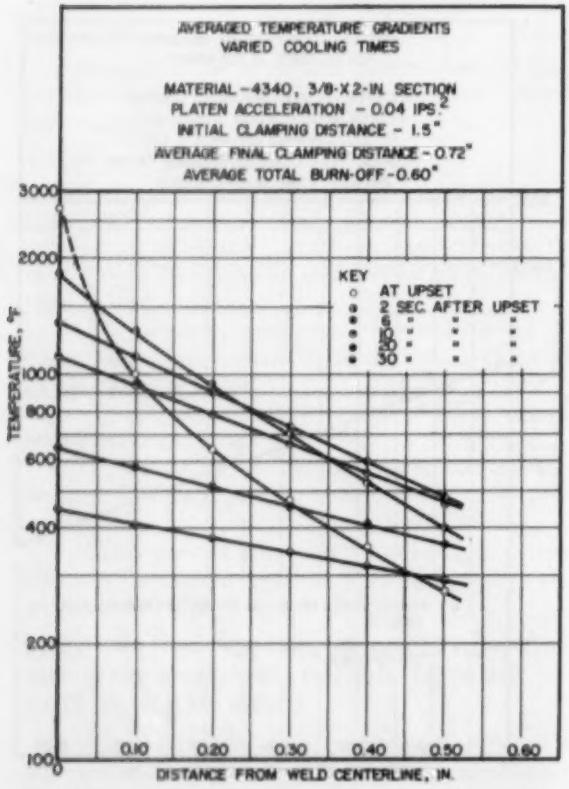

Fig. 3 Averaged temperature gradients—varied cooling times

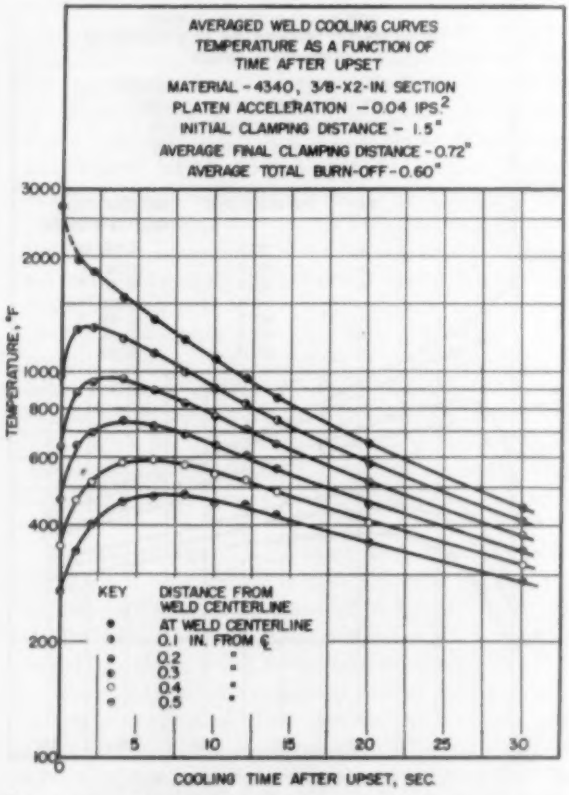

Fig. 4 Averaged weld cooling curves—temperature as a function of time after upset

Table 2—Dependence of Cooling Rate on the Upset Characteristics of the Steel Employed

Material: AISI 1020 and 4340 steel, 3/8-x 2.0-in. section.
Platen acceleration: 0.04 ips².
Initial clamping distance: 1.5 in.
Burn-off: Adjusted to produce the desired final clamping distance (in all cases 0.5 in. or greater total burn-off was employed).
Welding current cutoff at upset.

Material	*Specimen*	*Total burn-off, in.*	*Total upset, in.*	*Total platen travel, in.*	*Final clamping distance, in.*	*Upset force, kips*
1020	1	0.52	0.23	0.75	0.72	24.0
1020	2	0.52	0.27	0.79	0.70	23.6
1020	3	0.53	0.23	0.76	0.71	24.0
1020	4	0.54	0.23	0.77	0.70	24.0
4340	5	0.61	0.16	0.77	0.71	24.4
4340	6	0.61	0.16	0.77	0.71	24.4
4340	7	0.59	0.17	0.76	0.71	23.9
4340	8	0.60	0.17	0.77	0.73	23.5

Material	*Specimen*	*Average total burn-off in.*	*Average total upset, in.*	*Average final clamping distance, in.*	*Average upset force, kips*	*Weld centerline cooling rate, (° F/sec)* 1300° F	1000° F	900° F
1020	1–4	0.53	0.24	0.71	23.9	80	70	60
4340	5–8	0.60	0.17	0.72	24.1	80	60	50

intervals of cooling time had been plotted as indicated in Fig. 3, the next operation was to use these data to develop the averaged cooling curves illustrated in Fig. 4, using the technique outlined below:

1. Six arbitrarily chosen distances, 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5 in. were marked off on the temperature gradients such as are shown in Fig. 3.

2. The average temperature at each of these distances was obtained from the appropriate averaged temperature gradient for times of 0, 1, 2, 4, 6, 8, 10, 12, 14, 20 and 30 sec after upset, using the temperature gradient plots of which Fig. 3 is a typical example.

3. By replotting these values of average temperature as a function of time, a family of curves showing the average cooling behavior at the six arbitrarily selected distances from the weld line were obtained.

Figure 4, produced from Fig. 3 by the above technique, summarizes the average cooling behavior after upset for welds in AISI 4340 steel using 0.04 ips² platen acceleration, 1.5-in. initial clamping distance, 0.60-in. average total burn-off and an average of 0.085 in. per specimen upset.

Those curves of the family of averaged cooling curves which attained temperatures above the lower critical temperature, in both the AISI 1020 and 4340 steels, were replotted using an expanded scale and the average cooling rates at 1300, 1000 and 900° F were determined by the slope method.

Results of the Cooling Rate Comparison Study

A complete tabulation of the welding conditions employed for each flash weld in this portion of the investigation may be found in Table 2. As may be noted by inspection of this table, four duplicate welds were prepared in each of two steels, AISI 1020 and 4340, under similar welding conditions. Since some minor variation does exist in certain welding variables, the average value of each of the variables is also presented together with the average weld centerline cooling rate at 1300, 1000 and 900° F. It may be noted that the average total distance of flashing burn-off for the alloy steel specimens was 0.07 in. greater than for the welds in plain-carbon steel. However, the increased upset travel associated with the latter steel resulted in obtaining essentially the same final clamping distance for both groups.

Such control of the final clamping distance, platen acceleration and material thickness, the three primary variables which determine the cooling rate in flash welds,[2] should result in identical cooling conditions if the altered upset behavior of the alloyed steel is not of importance.

Because of the complex process involved in determining the cooling rates from the original thermal data, it is not possible to make an accurate estimate of the limits of error in the cooling rates obtained. However, it is believed that variations of the order of ±10° F/sec, such as are indicated in Table 2, are not great enough to be attributed to the difference in the upset characteristics of the alloy steel, and therefore, that the data obtained from welds in plain-carbon steels may be applied directly to the alloy steels.

This view is supported in light of the fact that the cooling rates obtained for the 1020 steel welds are slightly more rapid than those indicated by previous work,[2] but the difference is less than the probable experimental error. The plot of the weld centerline cooling rate as a function of the final clamping distance, which appeared in a previous report,[3] is shown in Fig. 5. The data for Fig. 5 were obtained from welds employing AISI 1020 steel of 3/8- x 2.0-in. section size at approximately the same rate of platen acceleration used

for the present investigation. At a final clamping distance of 0.72 in., Fig. 5 indicates the cooling rates at 1300, 1000 and 900° F to be, respectively, 80, 55 and 45° F/sec, which would show even greater similarity with the experimental results of the 4340 grade steel in the present study.

PART II REDUCTION OF THE COOLING RATE IN FLASH WELDS BY USE OF UPSET CURRENT

The steep temperature gradients and rapid rates of cooling characteristic of the flash welding process make it impractical to avoid the formation of martensite, in any steel of reasonable hardenability, by selection of the flashing variables.[2] It is conceivable, however, that by use of upset current the cooling rate might be reduced so that, at least in some steels of sufficiently low hardenability, the martensite transformation might be avoided. With steels of greater alloy content the reduction in the rate of cooling might be sufficient to reduce the percentage of brittle martensite produced.

The present generator, used to supply power for all of the welds described in this report, has a severe drooping characteristic and therefore is not suitable for supplying currents of the magnitude required for a complete study of postweld heat treatments. However, a preliminary study of the effect of upset current was performed in order to secure general information on the problem for later use when the new higher capacity motor-generator set is put into service.

Preparation of Specimens and Procedure for Obtaining Thermal Data

Thermal data on the effect of upset current were obtained using $^3/_8$- x 2- x 6-in. specimens of AISI 1020 steel. Four duplicate welds were made at a platen acceleration of 0.04 ips^2 with an initial clamping distance of 1.5 in., employing approximately 0.5 in. of total flashing burn-off. The maximum upset current obtainable with the existing power supply was employed, resulting in an average current density of the order of 18,500 amp/in.^{2} rms, for an interval of approximately 1.5 sec. The output of a current transformer in the primary circuit of the welder was led to the oscillograph to obtain a record of the magnitude and duration of the flow of upset current.

The thermocouple attaching technique and the pro-

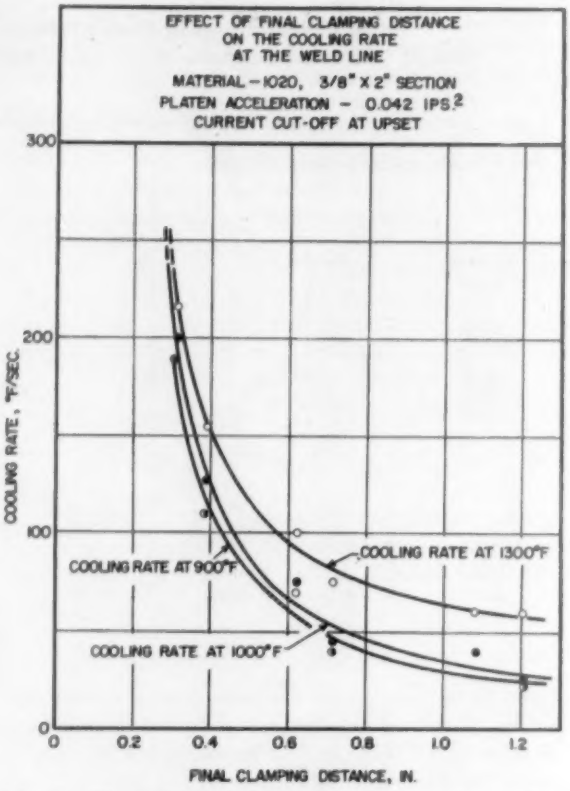

Fig. 5 Effect of final clamping distance on the cooling rate at the weldline

Table 3—Effect of Upset Current on Weld Centerline Cooling Rate

Material: AISI 1020 steel, $^3/_8$-x 2-in. section.
Initial clamping distance: 1.5 in.
Platen acceleration: 0.04 ips^2.
Upset current heat control: 100%.

Specimen	Total burn-off, in.	Total upset, in.	Final clamping distance, in.	Upset current density, amp/in.^{2}	Upset current duration, sec.	Upset force, kips
9	0.52	0.30	0.63	18,100	1.55	24.1
10	0.52	0.30	0.63	19,200	1.40	24.1
11	0.51	0.32	0.63	18,100	1.55	24.1
12	0.51	0.30	0.64	18,500	1.48	24.0

Average total burn-off in.	Average total upset, in.	Average final clamping distance, in.	Average upset current density amp/in.^{2}	Average upset current duration, sec.	Average upset force, kips	Weld centerline cooling rate, (° F/sec.) 1300 ° F	1000° F	900° F
0.52	0.31	0.63	18,500	1.49	24.1	75	50	45
Rate of cooling which would be anticipated with similar welding conditions and a final clamping distance of 0.63 in. without upset current (from Fig. 5)						90	60	55

cedure for averaging of the raw data were essentially the same as described in the previous section.

Results of the Study of Upset Current

A tabulation of the welding conditions employed for this group of specimens, together with the averaged cooling rate data may be found in Table 3. It may be seen that the amount of upset current employed for this group resulted in an average total upset distance of 0.31 in. Comparison with data in Table 2, for welds in AISI 1020 steel, will show this to be an increase of 0.07 in. over welds made under similar conditions without the use of upset current.

Thermal data obtained from welds employing upset current showed that the weld centerline rates of cooling were 75, 50, and 45° F/sec at 1300, 1000 and 900° F, respectively, for these welds in $^3/_8$-in. material, which were made at a platen acceleration of 0.04 ips^2 and reached a final clamping distance of 0.63 in. Reference to Fig. 5 will show that the corresponding cooling rates in welds with the same final clamping distance attained without the use of upset current were 90, 60 and 55 ° F/sec at 1300, 1000 and 900° F, respectively.

Though these results indicate a trend toward slower rates of cooling when upset current is employed, the reduction is not as great as had been anticipated. Since equivalent rates of cooling are known to produce equivalent structures in steel, information on the probable changes in weld-zone microstructure occurring with differences in cooling rate of the order indicated above may be obtained by reference to published Jominy data.

By reference to Fig. 6, a plot of the Jominy bar cooling rate at 1300° F as a function of distance from the water quenched end, it may be seen that a cooling rate of 90° F/sec at 1300° F may be found on a Jominy bar at a distance of slightly less than $^5/_{16}$ in. from the water quenched end. Similarly, a cooling rate of 75° F/sec may be found at a distance of slightly greater than $^5/_{16}$ in. from the water quenched end of a Jominy bar. Reference to the published Jominy hardenability band for 4130-H[7] reveals that this change in cooling rate from 90° F/sec to 75° F/sec at 1300° F produced by the application of 1.5 sec of upset current at 18,500 amp/in.^{2} would change the hardness in the weld zone by less than 2 R_c hardness points in 4130-H. That is, the hardness at a distance of slightly over $^5/_{16}$-in. as indicated by the Jominy hardenability band, differs by less than 2 R_c points from the hardness at a distance of slightly less than $^5/_{16}$ in. Since this difference in hardness is of the order of the experimental error encountered in routine hardness measurement, the upset current used in this study was of no use in reducing the hardness in the weld zone of 4130-H.

It remains to be seen, however, whether higher upset current densities and longer upset current duration will significantly reduce the cooling rate and therefore the weld hardness in 4130 steel. Certainly, in some steels of lower hardenability the application of upset current to reduce the cooling rate may be useful. However, it seems unlikely that any reasonable magnitude of upset current will ever prove useful in reducing the hardness of the weld zone in more hardenable steels such as AISI 4340.

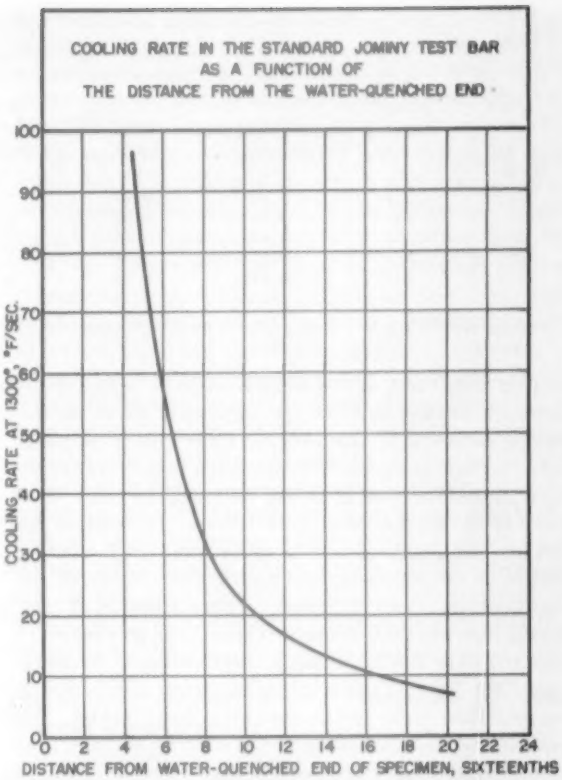

Fig. 6 Cooling rate in the standard jominy test bar as a function of the distance from the water-quenched end

With the 4340 steel the problem is complicated by the extremely high hardenability of this material. Even at a cooling rate of 40° F/sec at 1300° F, the minimum rate of cooling encountered in the previous study of cooling rates for welds without postweld treatment, the weldline structure would be fully martensitic. A cooling rate as low as 8° F/sec at 1300° F would still result in a structure of 90% martensite, and a cooling rate of less than 3° F/sec would be required to reduce the martensite to 50%. For comparison it might be noted that a similar 50% martensite structure could be obtained in the 4130 grade if a rate of 40° F/sec were employed. Therefore, it is considered to be impractical to attempt to slow the cooling rate by use of upset currents to a degree that will produce significant improvement in the weld-zone microstructure of 4340 steel.

PART III TEMPERATURE STUDIES DURING MACHINE TEMPERING

The relatively rapid cooling rates encountered in flash welding make the production of martensitic weld structures unavoidable in steels of medium and high hardenability such as AISI 4130 and AISI 4340.[8] In many applications the existence of hard brittle mar-

Results of Preliminary Studies of Temperature

operation to a more comprehensive study. The results

Table 4—Conditions Used for Preparing Specimens Tempered in the Welder

Materials: AISI 1020 steel, 3/8-x 2.0-in. section.
Platen acceleration: 0.04 ips².

Weld	Initial clamping distance, in.	Total burn-off, in.	Total upset, in.	Final clamping distance, in.	Upset force, kip	Cool time, sec	Temper current time, sec	Temper current density, amp/in.²
13	2.0	0.55	0.26	1.16	23.6	57	4.7	21,200
14	2.0	0.54	0.23	1.18	23.8	57	4.6	20,700
15	2.0	0.55	0.23	1.17	23.8	61	4.8	22,350
16	2.0	0.57	0.24	1.19	24.4	49	4.7	21,500
17	2.0	0.57	0.25	1.18	23.9	49	4.6	21,200

Average temper current density 21,400 amp/in.² obtained by use of 250-v field excitation on the welding supply generator.

tensitic structures in the weld zone have been experimentally proved to have no significant effect on the service behavior.[8] However, in some critical applications, it may be desirable to provide a tempering operation to reduce the hardness and improve the ductility of the weld zone microstructure. In order to determine the practicability of providing such tempering action in the machine, a comprehensive study of the operation has been proposed. This technique of tempering requires that the welded specimens be allowed to cool to below the martensitic transformation temperature (200–300° F) and then be subjected to a period of current flow while still in the jaws of the welder. By controlling the magnitude of the current and the time of current flow, and by taking into account the effects of specimen geometry, it should be possible to produce any desired short time tempering action in the weld zone. A similar technique in fact has been utilized successfully in improving the ductility of spot welds in high hardenability armor plate,[9] and should be equally applicable to flash welding.

Although it was recognized that the existing power supply was of inadequate capacity for conducting a comprehensive study of the effects of tempering in the machine, a preliminary investigation was undertaken. This was done primarily to develop suitable techniques for measuring the temperature distribution during tempering in anticipation of a more extensive investigation after the installation of the new power supply in the fall of 1954.

Preparation of Specimens and Experimental Procedure

All data on temperature distribution during tempering in the machine were obtained using specimens of 3/8- x 2.0- x 6-in. AISI 1020 steel, drilled for insertion of thermocouples as described in a previous section of this report. The magnitude of the temper current was determined from oscillographic records of the welding transformer primary current by multiplying the observed primary current by the welding transformer turns ratio. All tempering experiments were conducted using full phase (100% heat) welding current, since the maximum available current still fell short of the desired current. The average rms value of the temper current for the five runs was determined to be 16,050 amp, secondary current, corresponding to an average primary current of 299 amp rms. It should be noted that this value was the maximum continuous current available from the system then in use, and that currents 50 to 75% higher would be necessary for satisfactory machine tempering performance.

A tabulation of the welding and tempering conditions used for the welds made during this preliminary investigation may be found in Table 4. It will be noted that two different cool times were employed in this study, welds 13, 14 and 15 having been made using a cool time of 60 sec ± 5%, and welds 16 and 17 having been made with a shorter cool time after upset of 50 sec ± 5%. This was done in order to determine if the temperature at the beginning of the tempering cycle influenced the heating rate produced by a given set of conditions.

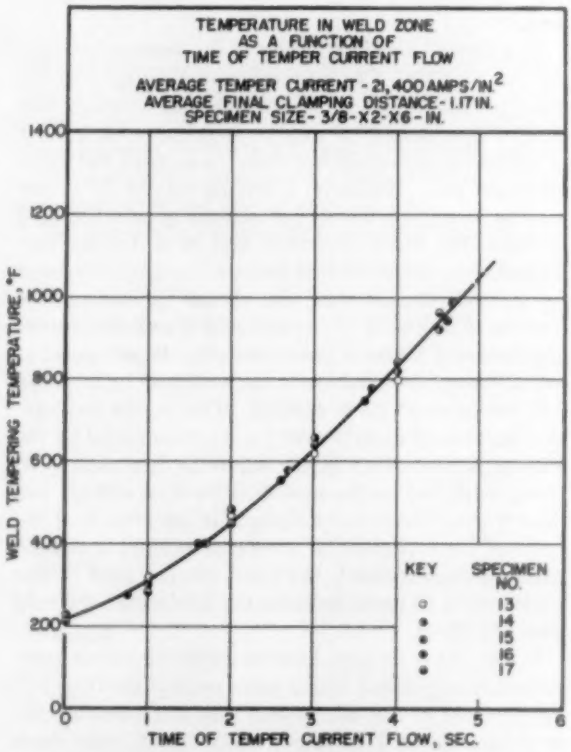

Fig. 7 Temperature in weld zone as a function of time of temper current flow

initiation of upset. Records were taken for a period of

Results of Preliminary Studies of Temperature Distribution During Machine Tempering

The results of the preliminary investigation confirmed the fact that the existing power supply was inadequate for a comprehensive study of machine tempering. Figure 7 indicates the change in temperature in the weld zone as a function of time of temper current flow. The data shown in Fig. 7 were taken from the five experimental runs tabulated in Table 4 and indicate that 4.75 sec of current flow at 21,400 amp/in.^{2} were required to raise the temperature from 200 to 1000° F. The time axis for the two welds (16 and 17) given the shorter cooling time was shifted in plotting to compensate for the additional 10 sec cooling time used with specimens 13, 14 and 15. That is, welds 16 and 17, having been cooled 50 sec ± 5% before application of the temper current had cooled to a temperature of approximately 300° F at the time of initiation of temper current. Welds 13, 14 and 15, however, were cooled 60 sec ± 5% before application of temper current and had cooled to a temperature of 200° F at the time of initiation of temper current. Therefore, the time axis of each of the five curves was shifted to the right or left in order to bring one point on each of the tempering temperature curves into coincidence. Since after this correction was made the data for all five specimens fell on a single curve, it was concluded that the rate of heating during flow of temper current was independent of the weld temperature at the time of initiation of temper current. If future investigation bears out this observation, it will be possible to determine experimentally the rate of heating of the weld zone as a function of:

1. Temper current.
2. Clamping distance.
3. Specimen geometry.

By suitable treatment of the data, the selection of an appropriate magnitude and time of temper current for producing a given weld tempering temperature may be possible where sufficient data have been obtained on the effect of the above variables.

The data obtained from these runs were not sufficient to establish the entire temperature distribution in the vicinity of the weld during tempering, but the indications are that the variation in temperature over a range of 0.4 in. on either side of the weld line is less than 50° F. If future work substantiates this indication, the variation should be small enough to permit satisfactory tempering action.

PART IV STUDY OF UPSET FORCE REQUIREMENTS

As a result of discussion at a meeting of the Flash Welding Advisory Committee, it was decided to subject the upset portion of the flash welding operation to a more comprehensive study. The results of the study of weld cooling rates[3] indicated the need for more information on the influence of the temperature gradient at the instant of upset on the upsetting action. In addition, the increased elevated-temperature strength of the more highly alloyed AISI 4130 and AISI 4340 steels caused variation in the upset distances obtained with the same machine settings, and the nature of this effect was therefore picked as a subject for further study.

It was determined that upset is a two-stage process characterized by an initial period of short duration, stage one, during which the upset force rapidly increases to a peak value and the major portion of upset occurs, followed by a second stage of slower deformation under essentially constant upsetting force. Stage two of upset may require a second or more for completion, and during this time the upset distance may be considered to vary linearly with time. Stage-one upset, however, occurs in a time interval of less than 50 msec during which the rate of upset decreases with time in a continuous fashion. This study has been largely restricted to stage one of the upset process, beginning at the time of initial application of upsetting force and ending at the instant when the peak pressure is exerted on the weld.

Specimen Preparation and Procedure for Obtaining Upset Data

Since it has been standard practice to obtain an oscillographic record of both the magnitude of the upset force and the distance of platen travel as functions of time for each of the experimental welds prepared during this investigation, only slight modification in this recording technique was required. An oscillograph-paper speed of 50 ips was necessary in order to obtain a suitable record of upset variables during the short time required for stage one of upset. To reduce the consumption of sensitized paper for recording purposes a microswitch connected to the movable platen was employed to start the oscillograph motor slightly in advance of the

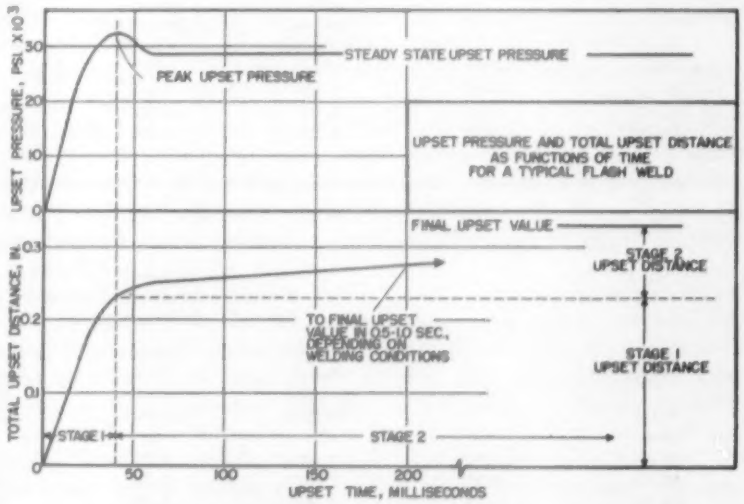

Fig. 8 Upset pressure and total upset distance as functions of time for a typical flash weld

points of maximum stress in the beam are employed, in

Table 6, employing the same three steels, except that

initiation of upset. Records were taken for a period of approximately 0.6 sec. Since this recording period was initiated after flashing had been established for several seconds and was completed while the specimen was still in the final, or stage two, portion of upset, a complete record of the weld cycle was not obtained. However, the final position of the platen and the value of the steady-state force were determined by obtaining an additional short record just before the completed weld was removed from the machine, and the amount of flashing burn-off was established from machine calibrations.

A total of eight groups of welds were prepared for this study. Each group was composed of five weld specimens flashed and upset under similar conditions to permit elimination of random errors. Four of the eight groups employed AISI 1020 steel and were flashed at platen accelerations of 0.120, 0.060, 0.008 and 0.004 ips^2 to determine the effect of changes in the temperature gradient established during flashing on the upset characteristics. Information on the effect of changes in the elevated-temperature strength of the material involved was obtained from the four remaining groups which employed alloy steels. One group of five welds in AISI 4130 steel and one in the AISI 4340 grade were prepared at a platen acceleration rate of 0.120 ips^2, and a similar set were flashed at an acceleration of 0.008 ips^2 in each steel. The initial clamping distance was held constant at 2.0 in., the flashing burn-off was maintained at approximately 0.50 in., and all material was of $^3/_8$- x 2-in. section size. Upset current was not employed for any of the welds in this study, current cut-off occurring in all cases within $^1/_2$ cycle after the initiation of upset.

As described in a previous section of this report, a provision was made in the design of the flash welder used at this laboratory to permit measurement of the platen force during upset as a function of time. In this machine the stationary platen is carried on roller bearings and the thrust on this platen is transmitted to a simply supported beam. SR-4 strain gages mounted at the

Table 5—Upset Characteristics as a Function of Platen Acceleration (Averaged Values from Appendix)

Material: 1020 steel, $^3/_8$-x 2-in. section.
Burn-off: 0.50 in. approx.

Weld nos.	*Initial clamping distance, in.*	*Platen acceleration, ips^2*	*Average final clamping distance, in.*	*Average* final total upset distance, in.*	*Average peak upset pressure, psi × 10^3*	*Average steady-state upset pressure, psi × 10^3*
19–23	2.00	0.120	1.29	0.21	35.5	..
24–28	2.00	0.060	1.24	0.26	32.9	..
29–33	2.00	0.008	1.16	0.34	32.4	29.1
34–38	2.00	0.004	1.12	0.38	31.4	..

* The average final total upset values shown above represent the average total upset at the end of Stage 2 of the upset process.

Table 6—Upset Characteristics as a Function of Steel Composition (Averaged Values from Appendix)

Material section size: $^3/_8$-x 2 in.
Platen acceleration: 0.008 ips^2.
Burn-off: 0.50 in. approx.

Weld nos.	*Steel*	*Average initial clamping distance, in.*	*Average final clamping distance, in.*	*Average* final total upset distance, in.*	*Average peak upset pressure, psi × 10^3*	*Average steady-state upset pressure, psi × 10^3*
29–33	1020	2.00	1.16	0.34	32.4	29.1
39–43	4130	2.00	1.25	0.25	34.4	30.0
44–48	4340	2.00	1.28	0.22	35.5	29.8

* The average final total upset values shown above represent the average total upset at the end of Stage 2 of the upset process.

Table 7—Upset Characteristics as a Function of Steel Composition (Averaged Values from Appendix)

Material section size: $^3/_8$-x 2 in.
Platen acceleration: 0.120 ips^2.
Burn-off: 0.50 in. approx.

Weld nos.	*Steel*	*Average initial clamping distance, in.*	*Average final clamping distance, in.*	*Average* final total upset distance, in.*	*Average peak upset pressure, psi × 10^3*	*Average steady-state upset pressure, psi × 10^3*
19–23	1020	2.00	1.29	0.21	35.5	..
49–53	4130	2.00	1.35	0.15	37.7	30.1
54–58	4340	2.00	1.36	0.14	40.2	31.0

* The average final total upset values shown above represent the average total upset at the end of Stage 2 of the upset process.

points of maximum stress in the beam are employed, in conjunction with a suitable bridge circuit, to furnish a signal proportional to the upset force to the recording oscillograph.

Results of the Study of Upset Requirements

Figure 8 shows a graphical representation of the variation in upset distance and upset pressure as functions of time, made using data taken from a typical flash weld. It may be noted from this figure that the upset pressure increases rapidly from the time of initiation and attains a peak value in a relatively short time, 40 msec in this case. The pressure rapidly decreases from the peak value to a slightly lower steady-state value which is only dependent upon the magnitude of the upset force available from the machine, and is not influenced by the upset characteristics of the steel employed or by the temperature distribution in the specimen prior to upset. The value of the peak pressure, however, can be shown to be a function of the resistance of the specimen to deformation during the early stage of upset and is therefore greater in welds which employ steels of increased elevated-temperature strength and those in which steep temperature gradients have been established during flashing.

During the interval prior to the instant of the peak value of upset pressure, the interval previously defined as "stage-one upset," over half of the total upsetting action occurs, and it is to this stage of upset that this report has been largely confined. The period during which the upset pressure decreases to the steady-state value and the upsetting action continues to completion at a much slower rate has been termed "stage-two upset." During stage two, the deformation occurs at an essentially constant rate and may require from one-half second to slightly more than one second for completion.

A complete tabulation of the welding conditions employed for each flash weld made for this portion of the report will be found in the Appendix. As may be seen by inspection of the tables of the Appendix, five duplicate runs were made with each combination of welding variables investigated. Minor variations in certain of the welding variables may be noted within each group of five duplicate welds; and therefore, the average value of each variable for all five duplicate runs was taken as representative of the group. Tables 5, 6 and 7 summarize the average value of each of the variables for each of the eight groups of five duplicate welds. Table 5 summarizes the data obtained on the upset characteristics of AISI 1020 steel as influenced by the stable-temperature gradient established during flashing by four different rates of platen acceleration. Table 6 shows the averaged values of both peak and steady-state upset pressure, and the final total upset distance obtained with welds in AISI 1020, 4130 and 4340 steels. All welds involved in the preparation of Table 6 were flashed at a platen acceleration of 0.008 ips^2 and, therefore, had identical temperature distributions at the instant of upset. The data of Table 7 were obtained from welds made under conditions similar to those shown in Table 6, employing the same three steels, except that the platen acceleration was increased to 0.120 ips^2 to obtain a steeper temperature gradient in the specimen.

Reference to Table 5 will show that the average peak pressure, attained during stage-one upset, increases with increase in the rate of platen acceleration. For example, an average peak value of 31,400 psi was measured for welds made using a platen acceleration of 0.004 ips^2, while the average peak upset pressure was found to be 35,500 psi with a platen acceleration of 0.120 ips^2.

Tables 6 and 7 show that the peak pressure is also dependent on the elevated-temperature strength of the steel employed. From these tables it may be observed that with the same platen acceleration, increasing alloy content results in a corresponding increase in the observed peak-pressure value. The average peak upset pressure measured in welds in AISI 4130 steel (welds 39–43) is given in Table 6 as 34,400 psi for specimens flashed at an acceleration rate of 0.008 ips^2. However, when the 4340 grade was employed at the same platen acceleration rate, Table 6 shows the resulting average pressure is increased to 35,500 psi. These data compare with a peak pressure value of 32,400 psi for AISI 1020 flashed at 0.008 ips^2. Increasing the platen acceleration rate to 0.12 ips^2 resulted in peak pressure values of 35,500, 37,700 and 40,200 psi for AISI 1020, 4130 and 4340, respectively, as may be seen by inspection of Table 7.

The observed changes in the peak pressure with increase in platen acceleration and with increase in the alloy content may be explained as follows:

1. At the termination of flashing, the upset action is initiated by application of the full-available steady-state upset force, a force of the order of 22,500 lb.
2. The movable platen accelerates rapidly, closing the gap between the flashing interfaces, and stage one of upset begins with the movable platen possessing considerable momentum.
3. The upset velocity decreases as the momentum of the moving platen is dissipated by the deformation of the weld specimens (see Fig. 8, lower curve).
4. As the resistance of the material to deformation in the upset zone increases with increasing upsetting action, the upset force transmitted to the beam backing up the fixed platen increases. This causes a corresponding increase in the measured upset force, and, therefore, in the effective upset pressure acting on the specimens, as shown in the initial portion of the upper curve in Fig. 8.
5. If the conditions are such that the momentum of the moving platen is dissipated over a comparatively long distance, the observed peak value of upset pressure is only slightly greater than the steady-state upset pressure produced by the available steady-state force. However, if the resistance to deformation increases rapidly with upset distance, the momentum of the moving platen is dissipated over a comparatively short distance, and a pronounced peak occurs in the curves of upset pressure as a function of time.

6. The occurrence of the peak in the upset pressure curve, visible in the upper curve of Fig. 8, corresponds to the transition between the initial rapid rate of upset, characterizing stage-one upset, and the slow steady rate of upset, characterizing stage-two upset.

7. Any factor which influences the rate of change of the resistance to deformation with upset distance therefore influences both the point of transition between stage-one and stage-two upset, and the magnitude of the observed peak pressure. For example, since the compressive yield strength of steel decreases with increasing temperature, the steepness of the temperature gradient has a pronounced effect on this transition and on the observed peak pressure. That is, increasing the platen acceleration rate, known to steepen the temperature gradient, causes the cooler, more resistant material to be located nearer to the flashing interface. Therefore, the stage-one to stage-two transition occurs at a lower value of upset distance, and causes a corresponding increase in the observed peak pressure. Similarly, higher alloy content, which causes an increase in the compressive yield strength of the steel at all temperatures, provides a general increase in the over-all resistance to upset for a given temperature distribution. This means, in turn, that for a given temperature distribution at the instant of upset, the more highly alloyed the steel, the smaller will be the upset distance at the stage-one to stage-two transition, and the higher the peak pressure at this transition.

8. Once the initial momentum of the moving platen is dissipated, the upset continues at a slow constant rate under the influence of the available steady-state upset force. During this interval, the heat, concentrated in the material extruded as flash during stage one, flows toward the jaws producing a gradual redistribution of temperature in the specimen, and permitting the slow constant rate of upset observed during the balance of stage two.

It is obvious that the above factors do not influence the steady-state pressure, which is dependent on the maximum available force of the machine itself, and it may be noted in Tables 6 and 7 that the average steady-state pressure was essentially constant for the five groups for which data are available, although the flashing acceleration rate and the material differs in these groups.

Figures 9, 10 and 11 are plots of the upset distance as a function of the upset time, and are of the same type as were seen in the initial portion of the lower curve of Fig. 8 for stage-one upset. In the latter three figures, however, the curves have been plotted slightly beyond

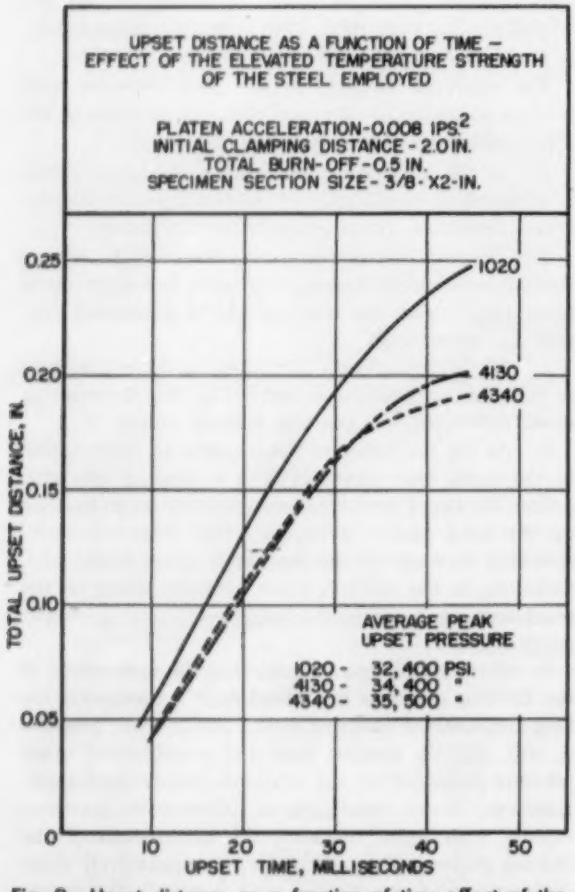

Fig. 9 Upset distance as a function of time effect of the elevated-temperature strength of the steel employed

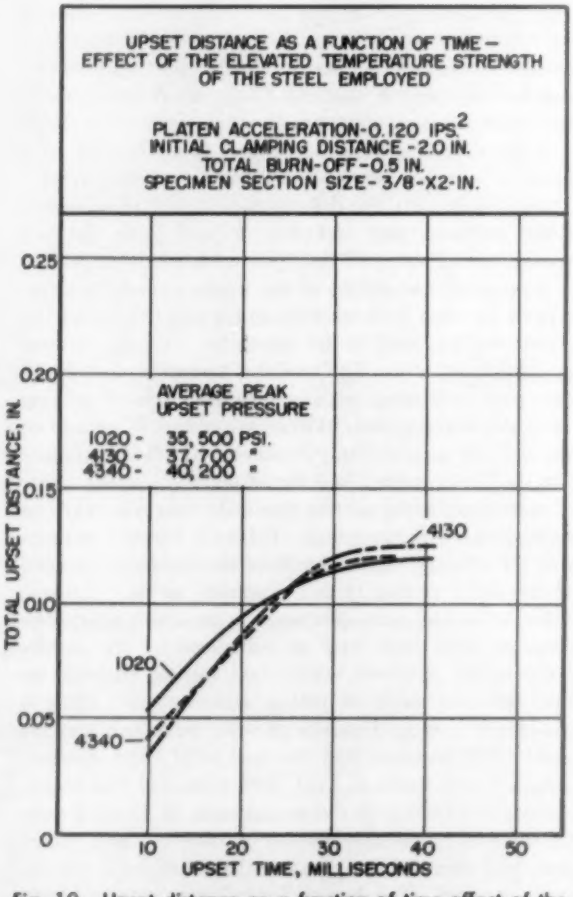

Fig. 10 Upset distance as a function of time effect of the elevated-temperature strength of the steel employed

the limit of stage one of upset which, as has been discussed previously, requires but 25–45 msec for completion. The curves of Fig. 9 were plotted from data obtained on welds in AISI 1020, 4130 and 4340 flashed at the relatively slow rate of platen acceleration of 0.008 ips² in order to establish a gradual temperature gradient in the specimens at the instant of upset. The curves in Fig. 9 illustrate the influence of differences in the elevated temperature strength of the steel employed on the total upset obtained in stage one. As this figure shows, after 40 msec of upset time the AISI 4340 steel, being the most highly alloyed, upset a total distance of 0.185 in., the unalloyed, AISI 1020 steel, upset a total distance of 0.235 in., and, after the same time, the AISI 4130, being intermediate in alloy content, upset a total distance of 0.195 in. As the table included in Fig. 9 reveals, the peak-pressures observed at the end of stage one varied as would be expected, being 32,400 psi for the AISI 1020, 34,400 psi for the AISI 4130 and 35,500 psi for the AISI 4340.

The effect of increased alloy content and the corresponding increase in resistance to deformation is partially masked by the more pronounced effect of the temperature gradient, as may be seen by inspection of Fig. 10 and comparison of this figure with Fig. 9. Figure 10 shows the total upset distance as a function of time for welds made with an initial clamping distance of 2.0 in., and a platen acceleration during flashing of 0.12 ips², using $^3/_8$- x 2.0-in. specimens of AISI 1020, AISI 4130 and AISI 4340 steels. Inspection of Fig. 10 reveals that little significant difference in the rate of upset may be attributed to composition, since the curves for the three steels are similar. However, comparison with the data shown in Fig. 9 reveals that the total upset produced in the first 40 msec has been reduced considerably (to approximately 0.12 in.) by increasing the platen acceleration during flashing to 0.12 ips². The observed peak pressure values reflect the influence of both alloy content and platen acceleration, however, being 35,500 psi for AISI 1020, 37,700 psi for AISI 4130 and 40,200 for the AISI 4340 steel. It should be noted that the observed magnitude of the peak pressures increases for increased alloy content as would be expected, and furthermore, that in each case the peak pressure is higher for the 0.12 ips² flashing acceleration than the corresponding value for 0.008 ips² flashing acceleration.

The marked effect of differences in temperature distribution prior to upset produced by different values of platen acceleration during flashing may be readily observed by reference to Fig. 11. This figure shows the relationship of upset distance with upset time for welds in AISI 1020 steel flashed at platen acceleration rates of 0.004, 0.008, 0.060 and 0.120 ips².

The stable temperature distribution existing at the instant of upset has been summarized in Table 8 for each of the four sets of flashing conditions used. The data in this table were obtained by the technique outlined in previous reports 1, 2 summarizing the influence of flashing variables on the temperature distribution at the instant of upset. As has been previously noted, the data presented in this table are equally applicable to all the steels used in the present investigation since the thermal and electrical properties of these steels are essentially identical.

Table 8—Calculated Stable Temperature Distribution at the Instant of Upset for Platen Accelerations Used in the Study of Upset Pressure Requirements*

Platen acceleration, ips²	*—Temperature at indicated distance, °F—* 0.05 in.	0.10 in.	0.15 in.	0.25 in.	0.35 in.
0.004 (approx.)	2700	2300	1850	1200	850
0.008	2650	2200	1650	1100	750
0.060	1450	1100	875	625	400
0.120	1250	900	750	500	325

* Obtained by method described in previous reports.[1, 2]

The technique for obtaining the data shown in Table 8 may be briefly summarized as follows:

1. A flashing parameter [1,2] was calculated for each set of flashing conditions, using the relationship:

$$\text{Flashing parameter} = \frac{\text{Platen acceleration during flashing (ips}^2\text{)} \times \text{Section thickness (in.)}}{\text{Initial clamping distance (in.)}}$$

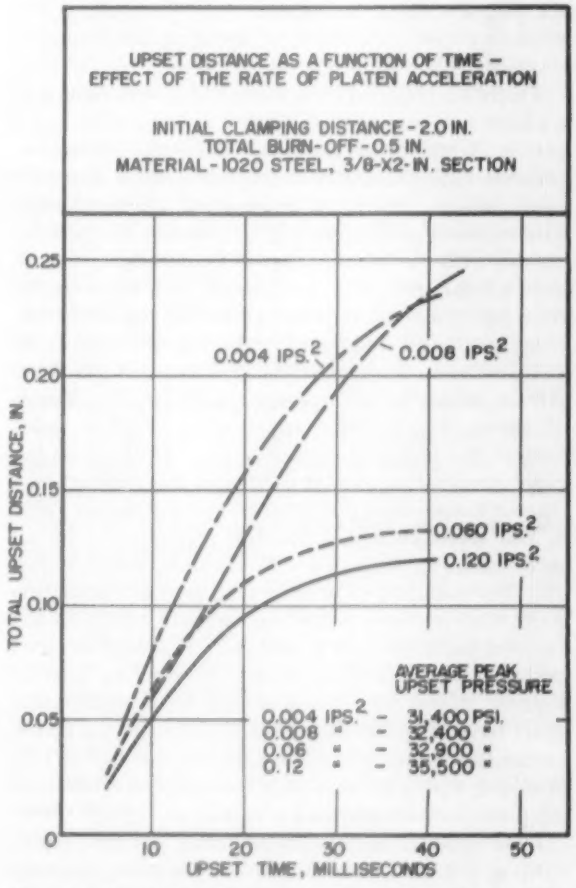

Fig. 11 Upset distance as a function of time effect of the rate of platen acceleration

2. The value of the flashing parameter is then located on the abscissa of the Summary Curve for Parabolic Flashing [1,2] which shows the temperature distribution as a function of flashing parameter.

3. The temperature distribution corresponding to a given flashing parameter is obtained from the family of curves constituting the Summary Curves.

As may be seem, from Fig. 10 and Table 8, the steep temperature gradient resulting from a platen acceleration of 0.120 ips^2 has limited the upset distance to 0.12 in. at 40 msec, while in the same time, 0.235 in. of upset travel occurs in welds which were flashed at 0.004 ips^2. Comparison of the temperature distribution data for the other two platen acceleration rates during flashing with the data shown in Fig. 11 reveals agreement with the expected results for the first 35 msec of upset.

The effect of the elevated-temperature strength of the material employed in flash welding on the upset pressure during stage one is illustrated in Figs. 12 and 13. In these figures, the experimentally determined upset pressure is plotted as a function of the total upset distance for AISI 1020, 4130 and 4340 steels. Since the upset pressure rises rapidly to a maximum at the end of stage one and then drops to the steady-state pressure value while stage two of the upset progresses, the curves of Fig. 12 and 13 have been terminated at the total upset distance which corresponds with the peak in the pressure curve. These curves, therefore, are limited to stage one of the upset process.

Figure 12, obtained from welds which were flashed at a platen acceleration of 0.008 ips^2 and therefore had a gradual temperature gradient, shows the increase in pressure requirements occurring in welds of increased alloy content. As would be expected, the upset pressure required to produce a given amount of upset increases with the alloy content. For example, to produce a total upset of 0.12 in., the AISI 4340, being the most highly alloyed, required 25,500 psi; the AISI 1020, being unalloyed, required 21,000 psi; while the AISI 4130, being intermediate in alloy content, required 24,000 psi, as may be seen by inspection of Fig. 12. Figure 13 shows that a similar relationship occurs in welds flashed at a higher acceleration rate. In this case the rapid acceleration rate of 0.120 ips^2 has resulted in a steeper temperature distribution, as tabulated in Table 8, and therefore higher pressure requirements for all three steels, as compared with the data shown in Fig. 12. For example, to produce 0.12 in. total upset, the AISI 4340 required 40,500 psi; the AISI 1020, 34,500 psi; and the AISI 4130, 37,000 psi. It should be noted that the average steady-state upset pressure was approximately 30,000 psi, corresponding to a steady-state upset force of 22,500 lb. Thus the effect of the platen momentum in extending the stage-one upset period by providing a peak pressure may be readily seen when the steep temperature gradient is employed.

Data obtained at acceleration rates of 0.004, 0.008, 0.060 and 0.120 ips^2 for welds in 1020 grade steel are shown in Fig. 14 to illustrate the influence of the rate of platen acceleration during flashing on the upset pressure

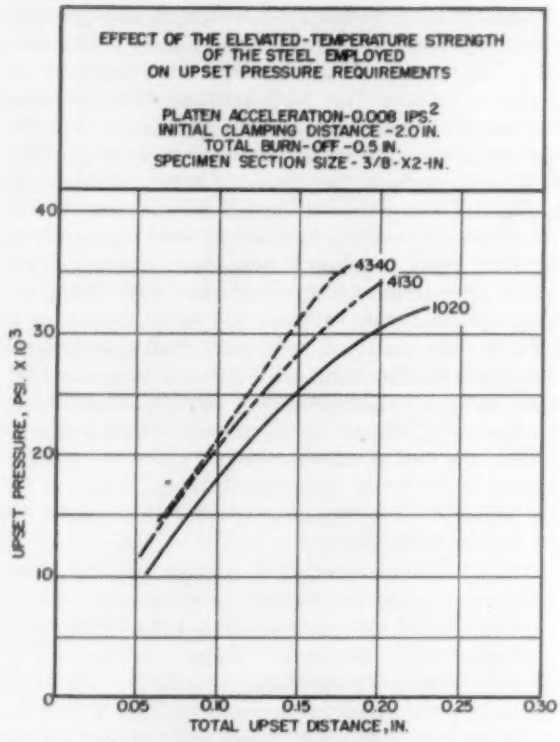

Fig. 12 Effect of the elevated-temperature strength of the steel employed on upset pressure requirements

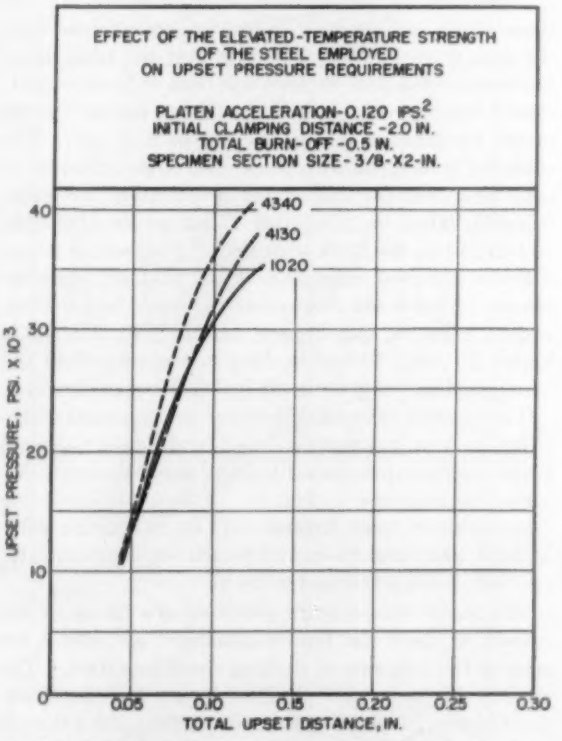

Fig. 13 Effect of the elevated-temperature strength of the steel employed on upset pressure requirements

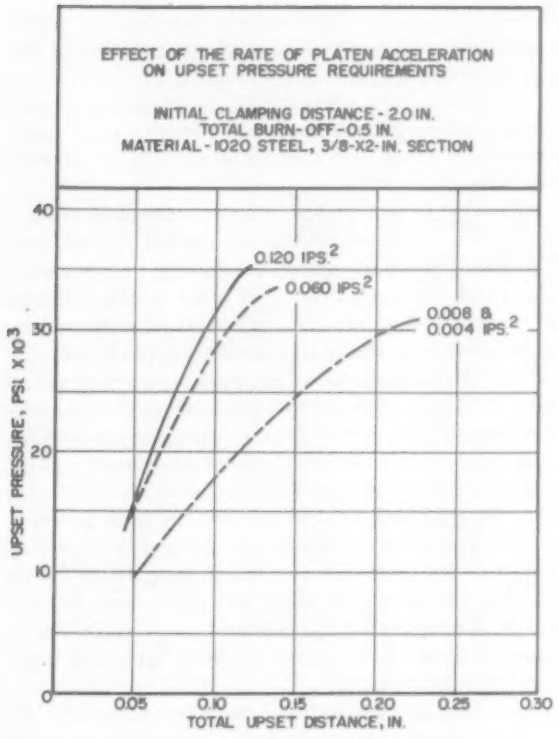

Fig. 14 Effect of the rate of platen acceleration on upset pressure requirements

requirements. In this figure the curves obtained at the two slowest rates of acceleration were so similar that they are presented as a single curve. All curves were plotted only for the duration of stage-one upset. Again choosing 0.12 in. of total stage-one upset as a basis for comparison, inspection of Fig. 14 reveals that an upset pressure of 35,500 psi would be required for 0.12 ips²; 32,000, for 0.06 ips²; and only 21,000 psi, for platen accelerations of 0.008 and 0.004 ips². The observed similarity between the upset pressure requirements with the two slowest platen accelerations may be explained by the fact that only a small difference in the temperature distribution is obtained by changing the platen acceleration from 0.004 ips² to 0.008 ips², as may be seen by reference to Table 8.

Table 9 lists the total upset produced during stage one and the average final total upset at the end of stage two of the upset process for AISI 1020 steel with various rates of platen acceleration during flashing. Table 10 shows similar data for AISI 1020, AISI 4130 and AISI 4340 steels flashed at platen accelerations of 0.12 ips² and 0.008 ips². Inspection of Table 9 reveals that between 50 and 70% of the average final upset was accomplished during stage one. Comparison of similar data for plain carbon and alloy steels in Table 10 reveals that at a given platen acceleration, a somewhat greater percentage of the total final upset was produced during stage one with the alloy steels.

Table 9—Comparison of Average Final Total Upset with Total Stage-One Upset

Platen accelerations: as indicated.
Material: 1020 steel, 3/8- × 2.0-in. section
Initial clamping distance: 2.0 in.
Average upset pressure: 30,000 psi.

Platen acceleration during flashing, ips²	*Total stage 1 upset, in.*	*Average final total upset, in.*	*Total final upset during stage 1, %*
0.004	0.23	0.38	60.5
0.008	0.23	0.34	67.8
0.060	0.13	0.26	50.0
0.120	0.11	0.21	52.5

Table 10—Comparison of Average Final Total Upset with Total Stage-One Upset

Material: as indicated.
Specimen size: 3/8- × 2.0-in. section.
Initial clamping distance: 2.0 in.
Average upset pressure: 30,000 psi.

Platen acceleration during flashing ips²	*Steel*	*Total stage 1 upset, in.*	*Average final total upset, in.*	*Total final upset during Stage 1, %*
0.120	1020	0.23	0.38	60.5
0.120	4130	0.12	0.15	80.0
0.120	4340	0.11	0.14	78.5
0.008	1020	0.23	0.34	67.8
0.008	4130	0.19	0.25	76.6
0.008	4340	0.18	0.22	81.8

No definite conclusions can be drawn from the available data regarding the effect of the temperature distribution on the ratio of stage-one upset to final upset distance. However, it is believed that an increase in the available upset force and therefore in available upset pressure would be helpful in evaluating this effect. Unfortunately, however, this cannot be realized with the present equipment, since the maximum available upset force was utilized throughout the investigation.

Summary and Conclusions

This report of experimental investigations on the flash welding of alloyed steels consists of four major sections.

I. Effect of the Composition of the Steel Employed on the Cooling Rate in Flash Welds

Weld centerline rates of cooling at 1300, 1000 and 900° F were detemined and compared for welds in AISI 1020 and AISI 4340 steels employing similar initial clamping distance, platen acceleration and section size. The effects of differences in upsetting behavior were minimized by adjusting the flashing burn-off to provide the same final clamping distance.

II. Reduction of the Cooling Rate in Flash Welds by Use of Upset Current

The weld zone cooling rates at 1300, 1000 and 900° F were experimentally determined for welds in 3/8- x 2- x 6-in. specimens of AISI 1020 steel which were subjected to 1.5 sec of upset current at an average current

density of 18,500 amp/in.^{2}. The reduction in the rate of cooling produced by this value of upset current was determined by comparison with previously determined cooling rate data for welds prepared without postweld treatment.

III. Temperature Studies During Machine Tempering

The temperature distribution in the vicinity of the weld zone in flash welds in steel on $^3/_8$- x 2-in. section size was measured during the application of 4.75 sec of temper current at an average current density of 21,400 amps/in.^{2}.

IV. Study of Upset Force Requirements

Welds were prepared employing three steels of differing elevated-temperature strength at platen accelerations of 0.120. 0.060, 0.008 and 0.004 ips^2 to determine the influence of the composition of the steel and the influence of the temperature gradient, established during flashing, on the upset force requirements.

The following conclusions were drawn from this investigation:

1. If the specimen geometry, platen acceleration and the final clamping distance are held constant, the cooling rate obtained in flash welds is not influenced by the composition of the steel employed.

2. For welds in $^3/_8$- x 2-in. section flashed at a platen acceleration of 0.040 ips^2 and upset to a final clamping distance of 0.63 in., the application of approximately 1.5 sec of upset current at an average density of 18,500 amp/in.^{2} rms resulted in a weld centerline cooling rate, at 1300° F, only 15° F/sec below the 90° F/sec rate obtained in welds prepared under similar conditions without upset current.

3. Further study is required to determine whether, in steels having hardenabilities equal to or less than that of AISI 4130, higher upset current densities and longer upset current duration may bring about a significant reduction in cooling rate and therefore in the as-welded hardness.

4. The extremely high hardenability of the 4340 steel makes it impractical to attempt to slow the weld-zone cooling rate sufficiently to reduce the as-welded hardness by use of upset currents.

5. A suitable technique was developed to measure the temperature distribution in the vicinity of the weld during machine tempering.

6. A temper current flow of 21,400 amp/in.^{2} applied for a time of 4.75 sec was required to raise the weld-zone temperature from 200 to 1000° F.

7. Results of the preliminary study indicate that the rate of heating during the flow of temper current is independent of the weld temperature at the time of the initiation of temper current.

8. If future investigation supports the above observation it will be possible to determine experimentally the rate of heating of the weld zone as a function of

   (*a*) Temper current.
   (*b*) Final clamping distance.
   (*c*) Specimen geometry.

9. When sufficient data have been obtained on the above variables it will be possible to select an appropriate time and magnitude of temper current to produce a given weld tempering temperature.

10. For the tempering conditions studied, at a maximum tempering temperature, the variation in temperature over a range of 0.4 in. on either side of the weld line is less than 50° F.

11. Upset was found to be a two stage process characterized by an initial, or stage-one, period of short duration during which the upset force rapidly rises to a peak value and the major portion of upset occurs, followed by a second stage of slower deformation under a constant upset force of slightly less than the peak value.

12. The magnitude of the peak upset pressure at the end of stage one is a function both of the temperature distribution in the specimens and the composition of the steel. Rapid rates of platen acceleration, which establish steeper temperature gradients, and increased alloy content both tend to increase the peak pressure.

13. The platen acceleration, previously shown to influence the temperature gradient established during flashing was shown to affect the upset force requirements during both stage one and stage two. Faster rates of platen acceleration result in increased upset force requirements.

14. During stage one and stage two upset, the upset force requirements were found to be greater for the alloyed steels, due to their greater elevated-temperature strength.

Acknowledgment

The authors wish to acknowledge the financial support provided this investigation by the Air Research and Development Command, Wright-Patterson Air Force Base, Ohio, under Contract No. AF18(600)-71. This project was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with R. E. Bowman acting as project engineer.

They also wish to acknowledge the advice and suggestions received from the Flash Welding Subcommittee of the Welding Research Council.

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APPENDIX

Tabulations of the welding conditions employed for each flash weld. Five duplicate runs were made with each combination of welding variables investigated. Average value of each variable for all five duplicate runs was taken as representative of the group. (See Tables A1, A2 and A3)

Table A1

Upset Characteristics as a Function of Platen Acceleration

Material: 1020 steel, $^3/_8$-x 2-in. section.
Burn-off: 0.50 in. approx.

Weld nos.	*Initial clamping distance, in.*	*Platen acceleration, ips²*	*Final clamping distance, in.*	*Total upset distance, in.*	*Peak upset pressure, psi × 10³*	*Steady-state upset pressure, psi × 10³*
19	2.00	0.120	1.28	0.22	36.1	
20	2.00	0.120	1.29	0.21	35.2	
21	2.00	0.120	1.28	0.22	36.8	
22	2.00	0.120	1.30	0.20	36.0	
23	2.00	0.120	1.31	0.19	33.4	
			1.29 avg	0.21 avg	35.5 avg	
24	2.00	0.060	1.23	0.27	33.4	
25	2.00	0.060	1.23	0.27	28.9	
26	2.00	0.060	1.24	0.26	34.2	
27	2.00	0.060	1.24	0.26	32.6	
28	2.00	0.060	1.25	0.25	35.5	
			1.24 avg	0.26 avg	32.9 avg	
29	2.00	0.008	1.16	0.34	32.3	29.2
30	2.00	0.008	1.14	0.36	32.4	29.3
31	2.00	0.008	1.16	0.34	32.3	29.1
32	2.00	0.008	1.15	0.35	32.3	28.9
33	2.00	0.008	1.17	0.33	32.8	29.2
			1.16 avg	0.34 avg	32.4 avg	29.1 avg
34	2.00	0.004	1.13	0.37	32.7	
35	2.00	0.004	1.11	0.39	29.6	
36	2.00	0.004	1.13	0.37	32.1	
37	2.00	0.004	1.12	0.38	31.2	
38	2.00	0.004	1.13	0.37	31.4	
			1.12 avg	0.38 avg	31.4 avg	

Table A2

Upset Characteristics as a Function of the Elevated Temperature Strength of the Steel Employed

Material section size: $^3/_8$-x 2 in.
Platen acceleration: 0.008 ips².
Burn-off: 0.50 in. approx.

Weld nos.	*Steel*	*Initial clamping distance, in.*	*Final clamping distance, in.*	*Total upset distance, in.*	*Peak upset pressure, psi × 10³*	*Steady-state upset pressure, psi × 10³*
29	1020	2.00	1.16	0.34	32.3	29.2
30	1020	2.00	1.14	0.36	32.4	29.3
31	1020	2.00	1.16	0.34	32.3	29.1
32	1020	2.00	1.15	0.35	32.3	28.9
33	1020	2.00	1.17	0.33	32.8	29.2
			1.16 avg	0.34 avg	32.4 avg	29.1 avg
39	4130	2.00	1.25	0.25	34.3	30.2
40	4130	2.00	1.25	0.25	34.2	29.9
41	4130	2.00	1.26	0.24	34.7	30.2
42	4130	2.00	1.25	0.25	34.8	29.9
43	4130	2.00	1.24	0.26	33.9	30.0
			1.25 avg	0.25 avg	34.4 avg	30.0 avg
44	4340	2.00	1.30	0.20	35.9	30.0
45	4340	2.00	1.28	0.22	35.0	29.6
46	4340	2.00	1.27	0.23	35.3	29.9
47	4340	2.00	1.27	0.23	34.7	29.6
48	4340	2.00	1.27	0.23	35.5	29.9
			1.28 avg	0.22 avg	35.5 avg	29.8 avg

9. When sufficient data have been obtained on the

April 1950.

Table A3

Upset Characteristics as a Function of the Elevated Temperature Strength of the Steel Employed

Material section size: $^3/_8$-x 2 in.
Platen acceleration: 0.120 ips^2.
Burn-off: 0.50 in. approx.

Weld nos.	*Steel*	*Initial clamping distance, in.*	*Final clamping distance, in.*	*Total upset distance, in.*	*Peak upset pressure, Psi × 10³*	*Steady-state upset pressure, psi × 10³*
19	1020	2.00	1.28	0.22	36.1	
20	1020	2.00	1.29	0.21	35.2	
21	1020	2.00	1.28	0.22	36.8	
22	1020	2.00	1.30	0.20	36.0	
23	1020	2.00	1.31	0.19	33.4	
			1.29 avg	0.21 avg	35.5 avg	
49	4130	2.00	1.34	0.16	38.3	30.9
50	4130	2.00	1.34	0.16	34.8	28.8
51	4130	2.00	1.34	0.16	37.8	31.5
52	4130	2.00	1.36	0.14	39.5	31.2
53	4130	2.00	1.35	0.15	38.3	32.0
			1.35 avg	0.15 avg	37.7 avg	30.1 avg
54	4340	2.00	1.36	0.14	40.8	32.0
55	4340	2.00	1.38	0.12	39.3	29.3
56	4340	2.00	1.35	0.15	41.1	31.1
57	4340	2.00	1.37	0.13	38.9	31.5
58	4340	2.00	1.35	0.15	40.0	31.2
			1.36 avg	0.14 avg	40.2 avg	31.0 avg

RESEARCH NEWS

(*Continued from page 215-s*)

CB&I Field Welding Laboratory Located at the Chicago Plant

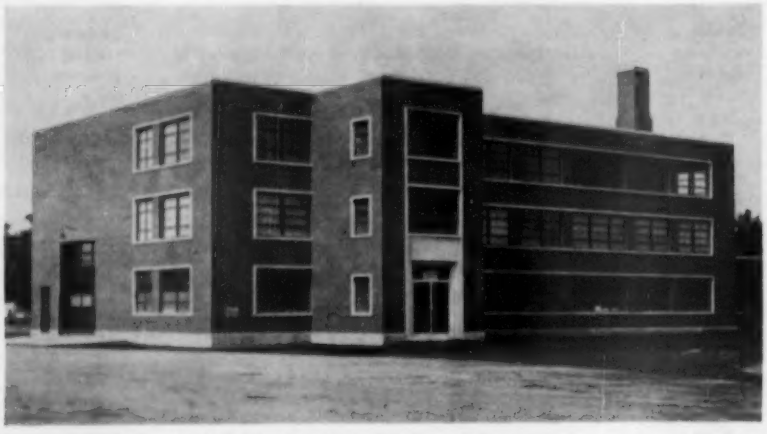

Fig. 1 Three-story Field Welding Laboratory building, 50 ft wide by 100 ft in length, used for welding research, testing and training, was completed on June 18, 1954

Only a few years ago most of the welding research was carried on by the manufacturers of welding equipment. Those were the days when fabricators were concerned primarily with the welding

Fig. 2 Laboratory's conference and classroom

(*Continued on page 250-s*)

THE STATIC AND FATIGUE BEHAVIOR OF SPOT-WELDED JOINTS IN TITANIUM

Spot-welded joints in tension-shear tests were stronger than similar joints in stainless steel and aluminum alloys. They were also stronger in fatigue tests as compared with aluminum alloys but somewhat lower than stainless steel

W. H. KEARNS, W. S. HYLER, AND D. C. MARTIN

ABSTRACT. A study of the spot welding of titanium and titanium alloys was made to determine the behavior of six-spot weldments under fatigue loading and to compare the fatigue behavior of similar weldments in titanium, aluminum and stainless steel. Commercially pure titanium sheet, commercial titanium—7% manganese alloy sheet, experimental unalloyed titanium sheet, and Type 321 stainless steel sheet, all of 0.040-in. thickness, were used. Static tension-shear and cross-tension tests were made on single-spot welds in the materials and the tension-to-shear ratios were calculated. For equal gages and spot spacing, six-spot joints in the stainless steel sheet were slightly better in fatigue than similar joints in the titanium materials under similar loading conditions. The joints in the titanium materials were significantly better than similar joints in clad 24S-T and 75S-T aluminum alloys. (The data on the aluminum alloys were developed in previous work.) Under static tension-shear loading, the joints in the titanium materials were stronger than similar joints in the stainless steel and the aluminum alloys.

Introduction

One of the many problems with which the user of titanium and titanium alloys is faced is that of making the joints which are necessary to fabricate useful structures. In the past few years, considerable attention has been given to the development of satisfactory arc-welding procedures for use with titanium. The properties of arc weldments made of titanium and titanium-alloy sheet have been studied in some detail. However, much less work has been done on spot welding. Studies of the properties of spot-welded joints in titanium have been restricted in most cases to properties under static loading. Little was known about the fatigue behavior of spot-welded joints in titanium and titanium alloys.

In September 1954, Battelle Memorial Institute completed studies of the properties of spot-welded joints in titanium and titanium-alloy sheets for the Wright Air Development Center. The objective of the research was to determine the fatigue behavior of multi-spot joints in titanium and titanium-alloy sheets, and to compare their behavior with that of similar joints in stainless steel and aluminum alloys. The static properties of several types of spot-welded joints also were studied. The results of the static tests were used to evaluate spot-welding schedules and as a base with which to compare the results of fatigue tests. This paper summarizes the important findings of the research.

W. H. Kearns, W. S. Hyler, and D. C. Martin are associated with the Battelle Memorial Institute, Columbus, Ohio.

Paper to be presented at AWS National Spring Meeting, Kansas City, Mo., June 7–10, 1955.

Summary

Two types of 0.040-in.-thick commercial titanium sheet and one experimental titanium sheet were used in this investigation. The two commercial sheets were commercially pure titanium having an ultimate strength of 73,000 psi and a heat-treated titanium—7% manganese alloy, having an ultimate strength of about 140,000 psi. The experimental sheet was unalloyed titanium that had an ultimate tensile strength of 53,000 psi. Annealed Type 321 stainless steel also was used in the experimental work.

Static tension tests were made on titanium and stainless steel single-spot specimens to aid in establishing welding conditions which would produce spot welds having diameters 4 to 5 times the thickness of the sheet, and to determine the tension-shear strength, cross-tension strength, and tension-to-shear ratio. The schedules selected for welding the test specimens were not necessarily the optimum ones for the materials and sheet gage. The results of the static tests showed that the spot welds in the commercially pure titanium sheet had a lower tension-to-shear ratio than previous work had predicted. Considerable work was done to determine the cause of the low tension-to-shear ratio. The results of this work indicated that quench hardening caused by rapid cooling from above the alpha-beta transformation temperature was to blame. However, the evidence obtained cannot be called conclusive and other influences, such as the pickup of oxygen and nitrogen, or the effect of other impurities in the sheet materials, also may have been at work.

The static tests also showed that postweld furnace heat treatments improved the static tensile properties

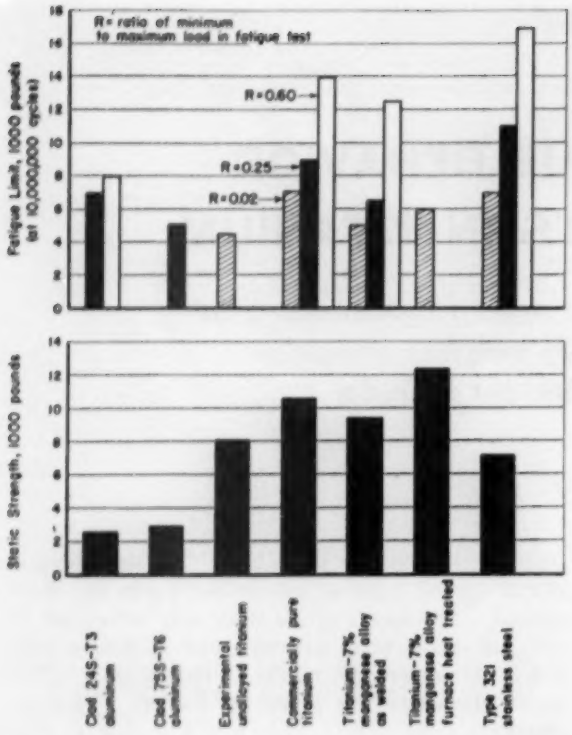
R = ratio of minimum to maximum load in fatigue test
R=0.60
R=0.25
R=0.02
Fatigue Limit, 1000 pounds (at 10,000,000 cycles)
Static Strength, 1000 pounds
Clad 24S-T3 aluminum
Clad 75S-T6 aluminum
Experimental unalloyed titanium
Commercially pure titanium
Titanium—7% manganese alloy as welded
Titanium—7% manganese alloy furnace heat treated
Type 321 stainless steel

Fig. 1 Comparison of static tension-shear strengths and fatigue limits of 6-spot lap joints in 0.040-in. titanium, stainless steel and aluminum alloy sheet

of spot welds in the titanium—7% manganese alloy sheet significantly. However, postwelding heat treatments made in the spot-welding machine did not improve the properties of welds in the alloy sheet.

The results of the static and fatigue tests of six-spot specimens in the titanium and stainless steel sheets are summarized in Fig. 1. The information gathered in this investigation shows that while weldments in Type 321 stainless steel had the highest fatigue limits, the fatigue limits of weldments in the commercially pure titanium sheet were not much lower. For the same sheet gage and spot spacing, the study shows that spot-welded joints in Type 321 stainless steel were slightly better in fatigue than similar joints in commercially pure titanium. Figure 1 also indicates that similar spot-welded joints in the titanium—7% manganese alloy sheet had fairly good fatigue behavior. However, it is known that as-welded spot welds and their heat-affected zones in the alloy sheet are brittle. This causes some doubt as to the usefulness of spot welds in the titanium—7% manganese alloy sheet. Some ductility was obtained in spot welds and the static strength of the alloy sheet was improved by a furnace heat treatment. However, the data available at present indicate that the heat treatment did not improve fatigue behavior.

The spot diameters and welding schedules for the aluminum-alloy specimens were not available. Therefore, it was not known if the spot welds were optimum for the gage and spot spacing. For the same spot spacing and sheet gage, spot-welded joints in commercially pure titanium sheet had better fatigue behavior than similar joints in the aluminum alloys for which data were abstracted from reports of previous work.[1]

Materials

Three types of titanium were chosen to represent the range of commercially pure titanium, an alpha-beta alloy, and an all-alpha alloy. Commercially pure titanium is a material with an ultimate tensile strength of 65,000 to 90,000 psi. It has good ductility and cannot be hardened by heat treatment. Alpha-beta titanium alloys have a wide strength range and the 7% manganese alloy used in this research was considered to represent high-strength commercial alloys. The strength of the 7% manganese alloy can be varied over a wide range by heat treatment. Both the commercially pure titanium and the 7% manganese alloy were purchased from a commercial supplier of titanium products. The all-alpha titanium—5% aluminum—$2^1/_2$% tin alloy was chosen to represent an intermediate-strength material. The properties of alloys of this type cannot be changed by heat treatment. At the time this alloy was needed it could not be purchased in sheet of the desired thickness. Consequently, an attempt was made to fabricate it at Battelle. Because of fabrication difficulties and lack of time, it was not possible to make sufficient static and fatigue tests on spot-welded joints in this alloy. Consequently, the results of tests that were made are omitted, since they were very inconclusive.

Table 1—Mechanical Properties of Titanium, Aluminum, and Stainless Steel Sheet

Sheet material	*Source*	*Thickness, in.*	*Yield strength, psi*	*Tensile strength, psi*	*Elongation in 2 in., %*	*Rockwell hardness*
Experimental unalloyed titanium*	Battelle	0.045	33,000	53,000	39	69 B
Commercially pure titanium	Commercial	0.040	68,500	73,000	27	99 B
Titanium—7% manganese alloy†	Commercial	0.040	133,000 to 143,000	139,000 to 154,000	15 to 20	28 C to 31 C
Type 321 stainless steel	Commercial	0.038	38,000	87,000	59	73 B
Clad 24S-T3 aluminum‡	...	Under 0.063	44,000	64,000	15	72 B
Clad 75S-T6 aluminum‡	...	Under 0.063	67,000	76,000	11	...

* Data are average for two heats of material.
† Material was supplied from six heats. Maximum and minimum values are shown.
‡ Typical properties.

Table 2—Composition of Titanium Sheet Materials

Sheet material	Alloying elements, weight %				
	Carbon	Oxygen	Nitrogen	Iron	Manganese
Experimental unalloyed titanium	0.01	...	0.003	0.13	...
Commercially pure titanium	0.14	0.12	0.027	0.12	...
Titanium—7% manganese alloy*	0.10 to 0.18	0.10	0.020 to 0.036	..	6.13 to 7.08

* Material was supplied from six heats. Maximum and minimum values of carbon, nitrogen and manganese are shown.

In the course of the research work, it was found that spot welds in the commercially pure titanium sheet did not have the static strength properties that previous work had indicated they should. In particular the cross-tension strength was much lower than had been expected. Unalloyed titanium sheet was prepared to aid in one phase of a study of the low tension-to-shear ratio. This sheet was much softer and had lower strength than the commercially pure sheet which had been purchased.

In addition to the titanium materials, annealed Type 321 stainless steel sheet was used in this work.

The mechanical properties of the various materials are given in Table 1. This table includes the properties of clad 24S-T3 and clad 75S-T6 aluminum sheet, since fatigue data for spot-welded joints in these alloys are used for comparison in later sections of this report. The compositions of the titanium materials are shown in Table 2.

Spot Welding

All of the spot welding during this investigation was done on a 200-kva, three-phase, low-frequency spot-welding machine. The machine has a maximum current output of 100,000 amp and a maximum electrode force of 10,000 lb. Down-slope current decay, postheat and forging force are available.

Variations in welding time and current were investigated to find suitable spot-welding schedules for the various materials. The welding forces used were chosen from previous experience. Welding schedules finally selected were ones which produced spot welds with diameters 4 to 5 times the thickness of the sheet. They did not necessarily produce spot welds of optimum geometry for the sheet gage and material. The schedules used are given in Table 3. Welding electrodes used for all welds were RWMA Class 2 copper alloy with 3-in. spherical radius faces.

Table 3—Spot-Welding Schedules

Sheet material	Welding time,* cycles	Heat control,† %	Electrode force, lb
Experimental unalloyed titanium	4	60	700
Commercially pure titanium	4	60	700
Titanium—7% manganese alloy	4	60	1000
Type 321 stainless steel	6	49	1000

* All welds made with one pulse of current.
† Maximum current, 50,000 amp.

A large number of spot welds were made in the titanium—7% manganese alloy sheet. These welds were given a postwelding heat treatment in the spot-welding machine. The machine heat treatments were as varied as was possible, but none had any beneficial effect on the weld properties. Therefore, a detailed description of these welding and heat-treating schedules has been omitted from this paper.

Three types of spot-welded specimens were made. Two of these were single-spot specimens. One was used for tension-shear tests and the other for cross-tension tests. Details of these specimens are shown in Fig. 2. Both specimens differ in size from those recommended by the AMERICAN WELDING SOCIETY. This change was made to conserve titanium. Some tests were made on standard-size specimens, and it was found that the test results were not significantly different from those obtained with the reduced-size specimens.

The third type of spot-welded specimen was a six-spot weldment. The details of this specimen are shown

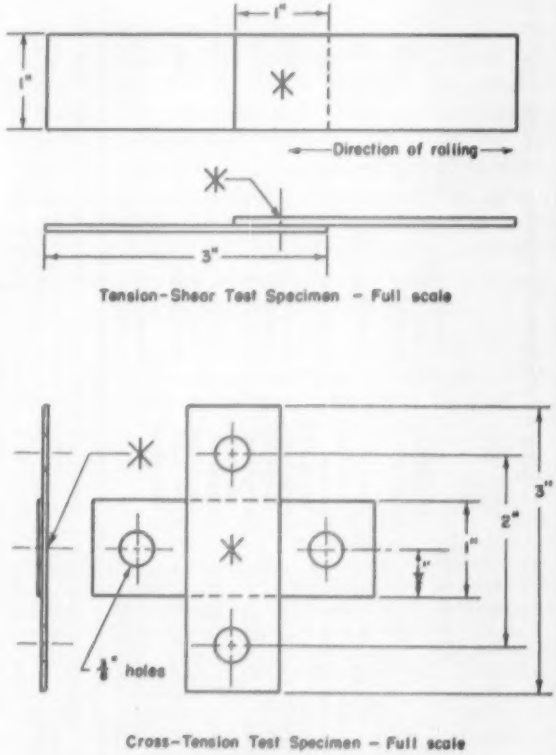

Fig. 2 Tension-shear and cross-tension test specimens

Table 4 Mechanical Properties of Single Spot Welds in 0.040-In. Titanium, Aluminum, and Stainless Steel Sheets

Sheet material		Condition of spot welds	Number of tension-shear tests	Tension-shear strength, lb.			Number of cross-tension tests	Cross-tension strength, lb.			Tension-to-shear ratio	Maximum weld hardness, Vhn
Type	Condition			Av.	Max.	Min.		Av.	Max.	Min.		
Experimental unalloyed titanium	Annealed	As-welded	10	1450	1500	1425	10	875	975	800	0.60	189
Commercially pure titanium	As-received (annealed)	As-welded	10	2080	2225	1575*	10	490	575	425	0.23	283
Commercially pure titanium	Vacuum annealed†	As-welded	5	2100	2175	2000	5	515	575	500	0.25	281
Commercially pure titanium	As-received (annealed)	Furnace heat treated‡	4	2150	2225	2075	4	700	730	625	0.33	247
Titanium—7% manganese alloy	As-received (annealed)	As-welded	8	2000	2150	1750	8	280	300	200	0.14	397
Titanium—7% manganese alloy	As-received (annealed)	Furnace heat treated‡	9	2200	2400	2100	10	560	625	475	0.26	294
Type 321 stainless steel	As-received (annealed)	As-welded	10	1220	1275	1150	10	940	1100	800	0.77	187
Clad 24S-T aluminum§	.....	As-welded	..	540 to 692	....	....	..	210 to 225	....	....	0.30 to 0.41	....
Clad 75S-T aluminum§	.....	As-welded	..	573 to 700	....	....	..	195 to 202	....	....	0.26 to 0.35	....

* This value was considerably lower than the average and the cause is unknown. The next higher value was 2050 lb.
† Held in vacuum at 1600° F for 2 hr and furnace cooled in vacuum.
‡ Held at 1400° F for 2 hr in flowing argon, furnace cooled to 1100° F, held for 2 hr and air cooled.
§ Data taken from paper by Hess, W. F., Wyant, R. A., and Winsor, F. J., "The Spot Welding of Ten Aluminum Alloys in the 0.040-In. Gage," THE WELDING JOURNAL, 25(8), 467-s to 484-s (1946). Values are upper and lower limits of range of values given.

Fig. 3 Spot-welded fatigue-test specimen

in Fig. 3. It was used for both static and fatigue tests.

Static tests were made on both single-spot and six-spot specimens. The tests on single-spot specimens were used first to determine the proper welding schedules for each type of material. After these were determined, a series of single-spot specimens was made in each material and used to determine tension-shear and cross-tension strengths. These values were used to calculate the tension-to-shear ratios. This ratio is sometimes used as a criterion of the ductility and quality of a spot weld. Tension-to-shear ratios less than 0.25 are usually thought to indicate welds which will have poor service behavior. The results of static tests on single-spot specimens are given in Table 4.

The commercially pure titanium and titanium—7% manganese alloy specimens were tested in more than one condition. When the single spot welds in the commercially pure sheet were tested in the as-welded condition, it was found that the tension-to-shear ratio was lower than expected. Previous work had shown that for spot welds in commercially pure sheet tension-to-shear ratios of 0.35 to 0.45 should be obtained.[2]

Properties of Single Spot Welds in Commercially Pure Titanium Sheet

A study of the composition of the commercially pure sheet was carried out to determine if there was some compositional variable which might be causing the low tension-to-shear ratio. It was found that the hydrogen content of the sheet was rather high (0.019 weight per cent). Lenning, Craighead and Jaffee have shown the deleterious effects that small amounts of hydrogen can

have on the properties of titanium, particularly on notch sensitivity and ductility.[3] Since the low tension-to-shear ratio was related to the low cross-tension strength, it was thought that the high hydrogen content and a resulting increase in notch sensitivity might be to blame. Consequently, some of the sheet was vacuum annealed by heating it at 1600° F in vacuum for 2 hr. This reduced the hydrogen content from 0.019 to 0.005%. However, spot welds made in the vacuum-annealed sheet did not have significantly better properties than ones made in the as-received sheet. Therefore, it appeared that it was not the presence of hydrogen that was causing the low cross-tension strength.

It was noticed that the hardness of the welds in the commercially pure sheet (both as-received and vacuum annealed) was considerably higher than the hardness of the as-received sheet (281 to 283 Vhn for spot welds, 220 Vhn for as-received sheet). The increased hardness of the welds might be a result of contamination by oxygen and nitrogen or a quench-hardening effect caused by the presence of some beta-stabilizing alloying element. Chemical analysis showed that the only common beta-stabilizing alloying element present in any significant amount was iron (0.13%). It was a normal amount for this type of material. However, some spot welds were given a heat treatment which was designed to remove the effects of quench hardening. When these spot welds were tested, it was found that the cross-tension strength was significantly higher than had been obtained from as-welded specimens. Since the tension-shear strength did not change, the tension-to-shear ratio was higher (0.33 compared to 0.23). These results indicate that quench hardening was having some effect on the spot-weld properties, although it is difficult to see how the small amount of iron present could have caused a significant amount of hardening.

One other compositional variable might have had some effect on the cross-tension properties. This is the rather high oxygen and carbon contents of the commercially pure sheet. However, hardness increases caused by these elements or by oxygen and nitrogen picked up during welding should not be affected by a postweld heat treatment. Consequently, it must be said that, at present, the reasons for the low cross-tension strength and low tension-to-shear ratio in the commercially pure sheet are not understood.

Because of the test results which were obtained on the commercially pure sheet, it was decided to obtain some unalloyed titanium sheet which had lower strength and hardness. This was done by fabricating the sheet from a cast titanium ingot. This ingot was made from selected sponge and the sheet had a hardness of 125 Vhn compared to 220 for the commercially pure sheet. As shown in Table 4, spot welds made in this sheet had significantly higher cross-tension strength but lower tension-shear strength than welds in commercially pure sheet. This made the tension-to-shear ratio for welds in the experimental sheet very high (0.60). One thing to note is that the welds in the experimental sheet also had much higher hardness (189 Vhn) than the sheet. In this respect, the experimental sheet behaved the same as the commercially pure sheet.

Properties of Single Spot Welds in Titanium—7% Manganese Alloy Sheet

Before the spot welds in the titanium—7% manganese sheet were tested, it was realized that both the weld and the surrounding heat-affected zone would be hard and brittle. This is caused by the quench from above the alpha-beta transformation temperature which the weld and heat-affected zone undergo. The effect of the quench can be at least partially eliminated by proper postwelding heat treatment. In this work, the weldments were heated at 1400° F in argon for 2 hr, furnace cooled to 1100° F and held for 2 hr, and then air cooled. The effect of this treatment is shown by the data in Table 4. Weld hardness was reduced from 397 Vhn to 294 Vhn. The tension-shear strength was increased by the heat treatment, but the cross-tension strength was increased much more, proportionally. This resulted in a considerably higher tension-to-shear ratio.

Metallographic Studies of Spot Welds

Thorough metallographic studies of spot welds in the various materials and various conditions were made. The structures of the welds, heat-affected zones, and base materials were normal for the materials and treatments used. No correlation between the results of the metallographic studies and fatigue behavior was found.

Properties of Six-Spot Joints in Titanium

The static strength properties of six-spot lap joints were determined for comparison with the results of single-spot tests and as base data for comparison with fatigue tests. The results of the tests are given in Table 5. The values for spot welds in aluminum are included for comparison.

If the per-spot values are compared with the tension-shear results for single-spot specimens given in Table 4, it will be noted that the values for the six-spot specimens in titanium and stainless steel sheet were about 10% lower than the values for the single-spot specimens.

Table 5—Static Tension-Shear Strength of Six-Spot Lap Joints

Sheet material	*Weld condition*	*Av. tension-shear strength, lb** *Total*	*Per spot*
Experimental unalloyed titanium	As-welded	8,100	1350
Commercially pure titanium	As-welded	10,700	1780
Titanium—7% manganese	As-welded	9,400	1560
Titanium—7% manganese	Furnace heat treated	12,300	2040
Type 321 stainless steel	As-welded	7,100	1180
Clad 24S-T aluminum†	As-welded	2,700	440
Clad 75S-T aluminum†	As-welded	2,900	480

* Averages of 3 to 5 specimens.
† Data from Reference 1.

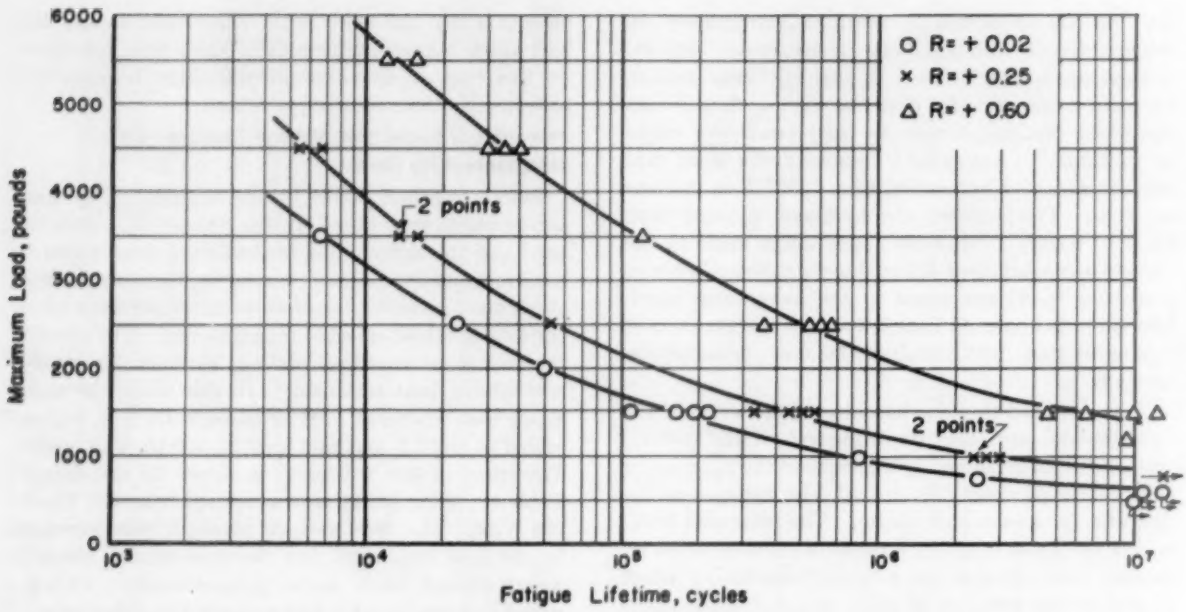

Fig. 4 Axial-load fatigue-test results on 6-spot lap joints in 0.040-in. commercially pure titanium

To make sure that this was not a result of specimen geometry, a number of six-spot specimens were made from commercially pure sheet and sheared into $^3/_4$-in.-wide single-spot tension-shear specimens. These specimens and a number of $^3/_4$-in.-wide single-spot specimens that were welded individually were tested at the same time. It was found that the first spot weld made in the six-spot specimens had about the same tension-shear strength as the single-spot test specimens. The remaining spot welds from the six-spot specimens had lower tension-shear strengths. It appears that shunting of a portion of the welding current through the preceding weld was responsible for the lower strength of the second and subsequent welds. No attempt was made to adjust for the effect of shunting when the fatigue specimens were welded.

Fatigue Tests

All fatigue tests were made on six-spot specimens. These were tested in tension-tension on Krouse direct-stress testing machines of 10,000-lb. capacity. Load-sensing devices stopped the machines when the maximum test load decreased from the preset value. This occurred, for example, upon the formation of a macroscopic fatigue crack. The machines were adjusted to stop when the maximum load decreased 40 lb.

Three load ratios were used, although fatigue tests were not made on welded joints of all types of material at all three load ratios. The load ratios were +0.02, +0.25 and +0.60.

Results of Fatigue Tests

The results of the fatigue tests on six-spot joints in commercially pure titanium sheet are shown graphically as S-log N curves in Fig. 4. The points plotted in this figure show the distribution of the specimens tested (10 to 15 specimens for each S-log N curve), and the curves are typical for all of the tests made during the course of this investigation. The results of all fatigue tests are plotted as S-log N curves in Figs. 5, 6 and 7. Curves for welded joints in clad 24S and clad 75S aluminum are also included in these figures.[1] All of the

Table 6—Estimated Fatigue Limits for Six-Spot Joints in Titanium, Stainless Steel, and Aluminum Sheets

		Estimated fatigue limits at 10^5 cycles					
		R = +0.02		R = +0.25		R = +0.60	
Sheet material	Spot-weld condition	Total, lb	% of static strength*	Total, lb	% of static strength*	Total, lb	% of static strength*
Experimental unalloyed titanium	As-welded	450	6	...	...	...	...
Commercially pure titanium	As-welded	700	7	900	8	1400	13
Titanium—7% manganese	As-welded	500	5	650	7	1250	13
Titanium—7% manganese	Furnace heat treated	500	4	...	...	...	...
Type 321 stainless steel	As-welded	700	10	1100	16	1700	24
Clad 24S-T aluminum	As-welded	...	...	700	25	800	30
Clad 75S-T aluminum	As-welded	...	...	500	17	...	...

* Estimated fatigue limit in terms of percent of static strength of six-spot specimen.

curves are what are believed to be a good fit to the data obtained. By using these curves, an estimate of the fatigue limit at 10^7 cycles was made. The estimated fatigue limits are given in Table 6. This table also reports the fatigue limit as a percentage of the static strength of six-spot specimens.

Studies of Fatigue Failures

During the investigation, a study was made of the fatigue failures in six-spot specimens of commercially pure titanium, titanium—7% manganese alloy, and Type 321 stainless steel sheet. The fatigue failures of spot welds in the aluminum alloys had been studied previously.

Titanium

Visual examination (low-power microscope), X-ray examinations, and metallographic examinations were

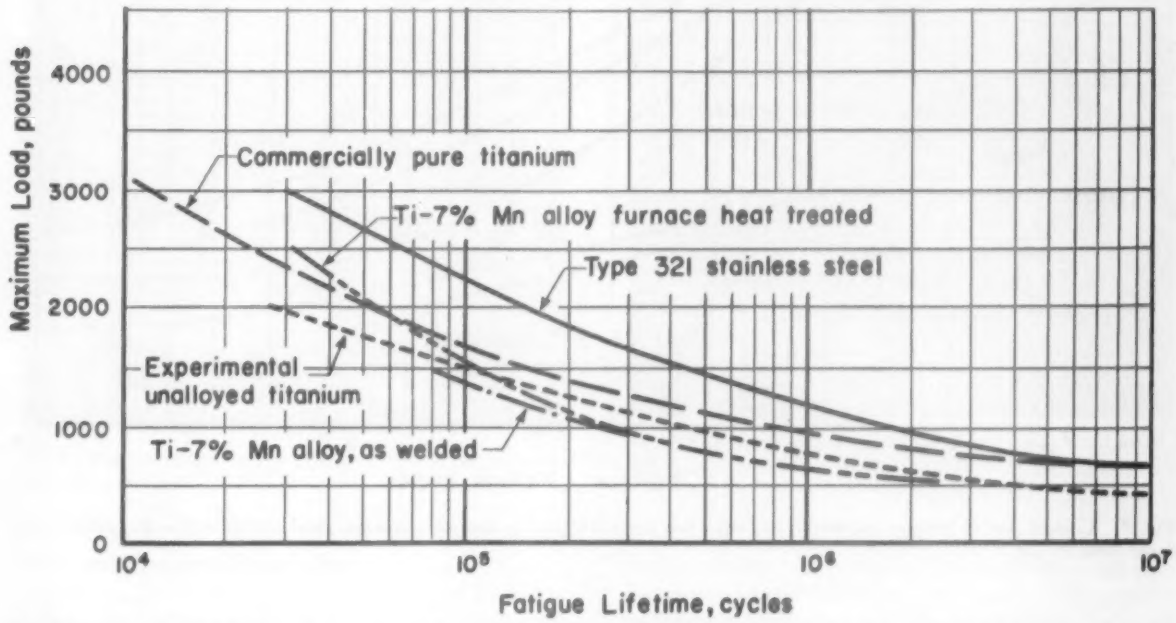

Fig. 5 Comparison of fatigue-test results of 6-spot lap joints in 0.040-inch titanium and stainless steel sheet at a load ratio of 0.02

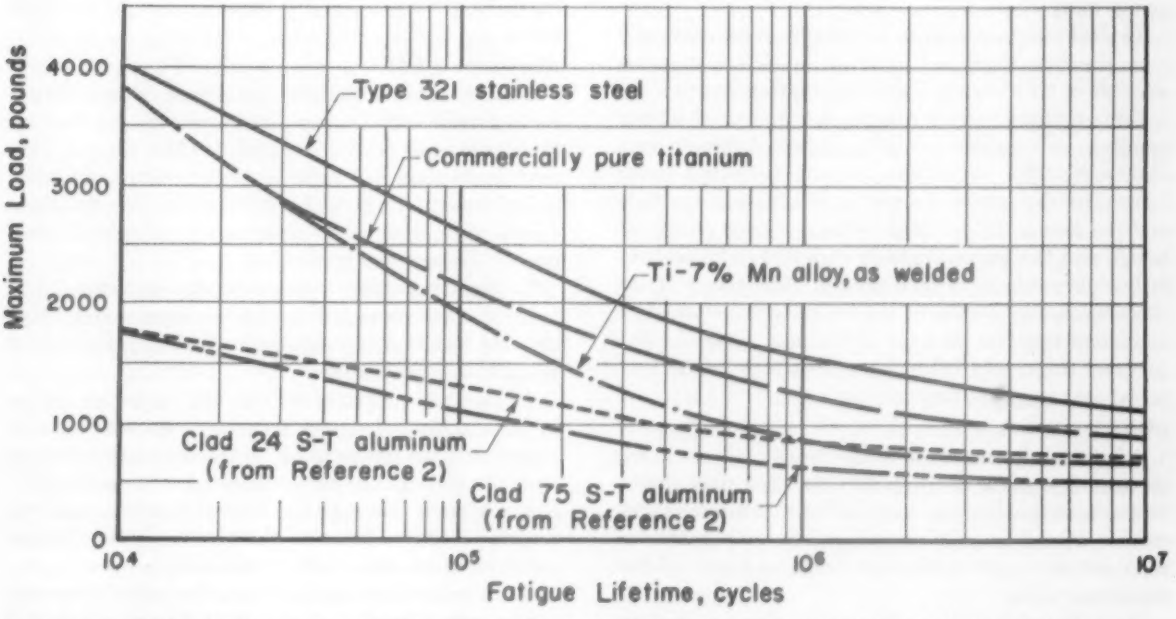

Fig. 6 Comparison of fatigue-test results of 6-spot lap joints in 0.040-in. titanium, stainless steel and aluminum alloy sheet at a load ratio of 0.25

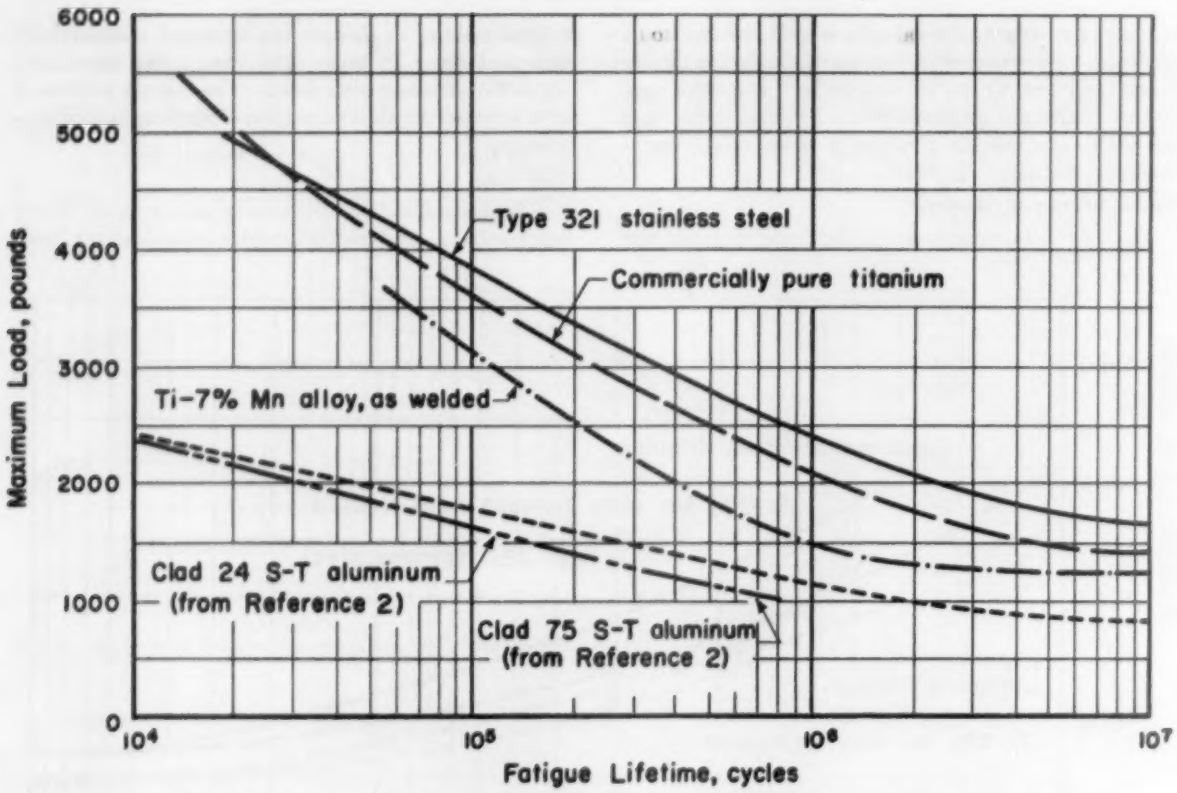

Fig. 7 Comparison of fatigue-test results of 6-spot lap joints in 0.040-in. titanium, stainless steel and aluminum alloy sheet at a load ratio of 0.60

made on representative failed spot welds in commercially pure titanium sheet and titanium—7% manganese alloy sheet.

Typical fatigue cracks in spot welds in commercially pure titanium sheet and in titanium—7% manganese alloy sheet are shown in Figs. 8 and 9, respectively.

Some similarities in the origin and growth of fatigue cracks in spot-welded joints in the two materials were observed. The origin was essentially in the notch formed by the extruded metal at the edges of the weld and the faying surface of the sheet. It is a sharp vee notch, and the region might be expected to be particularly vulnerable to fatigue failure. For either of the sheet materials, growth of the fatigue crack showed no consistent trend on the basis of lifetime. Thus, for any lifetime, the cracks might progress either in the base metal or through the heat-affected zone.

Stainless Steel

A brief study was made of the fatigue failures in the six-spot lap joints in Type 321 stainless steel sheets. Visual examination was made of all the fatigue specimens. Metallographic examination was made of representative spot welds that failed at high and low maximum loads.

It was found that the nuclei of the fatigue cracks were at the notch formed between the two sheets at the edge of the corona bond of the welds. The cracks progressed outward toward the sheet surfaces at the edge of the heat-affected zones on the tension sides of the spot welds.

Aluminum Alloys

A rather detailed study of the fatigue failures of spot welds in clad 24S-T aluminum alloy was reported by McMaster and Grover in 1947.[4] (The fatigue tests were made under the same research program described in Reference 1.) Five characteristic modes of fatigue failure were observed in aluminum spot-welded specimens. These were as follows:

1. Shearing of the nugget at the faying plane.
2. A crack propagating from the inner extremity of the clad inclusion through the weld nugget and parent metal to the sheet surface.
3. A crack propagating from the nugget periphery at the interface along the boundary between the weld nugget and the parent alloy (in the heat-affected zone) and then through the parent material to the surface.
4. A crack propagating from the interface at the nugget extrusion between the faying planes through unaffected base metal to the outer sheet surface.
5. A crack propagating from the outer extremity of the corona bond at the interface through unaffected base metal to the outer sheet surface.

Fig. 8 Typical fatigue crack at a spot weld in commercially pure titanium sheet. X 100

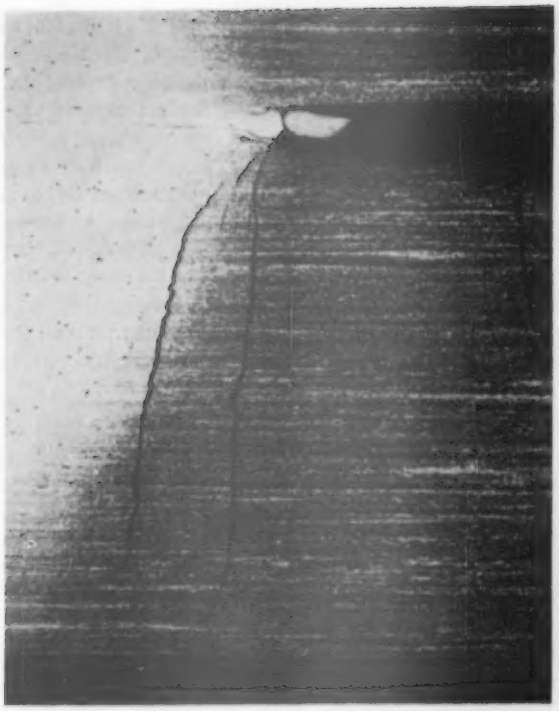

Fig. 9 Typical fatigue cracks at a spot weld in titanium–7% manganese alloy sheet. X 100

Discussion of Results of Fatigue Tests

The results of the fatigue tests of the multispot joints in the titanium materials indicate that the fatigue properties are influenced primarily by the strength and ductility of the base sheet. The properties of the weld nugget and heat-affected zone do not appear to have much influence on fatigue behavior. For example, there seems to be no relation between the tension-to-shear ratio and fatigue limit at any of the stress ratio used in the fatigue tests. Weldments of the titanium—7% manganese alloy had the same fatigue limit in both the as-welded and heat-treated conditions, while the tension-to-shear ratios in the two conditions were quite different (0.13 to 0.26). If the results of fatigue tests on weldments in the commercially pure and experimental unalloyed sheet are compared, the lack of correlation between the tension-to-shear ratio and fatigue limit is again evident. In this case, the material with the much higher tension-to-shear ratio (0.60 as compared to 0.23) had the lowest fatigue limit (450 lb as compared to 700 lb). If comparisons are made between fatigue limit and other properties of spot-welded joints, this same lack of correlation is evident.

The studies of the mode of failure in the fatigue tests showed that failure (in titanium and stainless steel weldments) always started in the base plate and was related to the geometry of the specimen rather than the metallurgical structure. The notch formed by the extruded metal and the faying surface of one of the sheets seemed to be the point at which the fatigue crack always started. Once started, these cracks would progress to the outer surface of the sheet without seeming to follow a preferred path. In some cases, the crack progressed through what seemed to be unaffected base metal, in other cases through a heat-affected zone. In no case did the crack enter the weld nugget. Therefore, it appears that the stress pattern imposed by the geometry in the vicinity of the spot weld and the properties of the unaffected base metal govern the fatigue limit of spot-welded joints in titanium.

The results of the fatigue tests indicate that the fatigue limit increases as the base-metal strength increases and also as the ductility increases. Thus, since the ductility of a metal usually decreases as strength increases, there should be some optimum combination of strength and ductility which produces the maximum fatigue limit. For the titanium materials used in this research, the optimum seems to be the commercially pure titanium sheet. The experimental unalloyed sheet is more ductile but has lower strength and a lower fatigue limit. The titanium—7% manganese alloy sheet is stronger but has lower ductility and a lower fatigue limit.

The sheet gage and spot spacing for the titanium materials and the stainless steel were the same as those for the aluminum alloys studied previously. Therefore, it is possible to compare the three materials from the standpoint of the behavior of similar multispot joints in the same sheet gage. In fatigue, stainless steel is stronger than commercially pure titanium,

titanium—7% manganese alloy, and clad aluminum alloys 24S-T and 75S-T. Furthermore, the commercially pure titanium is better than the aluminum alloys.

It must be admitted that the fatigue data for the weldments in the titanium—7% manganese alloy indicate that their fatigue behavior is not too bad when compared with similar joints in stainless steel and aluminum. However, there is some reluctance to accept this evidence at face value, since it has been shown that the spot welds in the titanium alloy are very brittle. On the other hand, spot welds in the commercially pure sheet are ductile, and the fatigue data can be used for comparison with greater confidence.

Conclusions

From the results of the static and fatigue tests on spot-welded joints in unalloyed and alloyed titanium, stainless steel, and aluminum, the following conclusions were made.

1. Spot-welded joints in the high-strength titanium —7% manganese alloy sheet had somewhat poorer fatigue strengths than similar joints in average strength, commercially pure titanium sheet of the same gage.

2. Furnace heat treatment did not improve the fatigue behavior of spot-welded joints in the titanium—7% manganese sheet. However, furnace heat treatment improved the static behavior of the joints significantly. Machine postweld heat treatment of spot welds in the alloy sheet did not improve their behavior in static tests. Postweld heat treatments made in the spot-welding machine probably would not improve the fatigue behavior of joints in titanium—7% manganese alloy sheet.

3. Sheet gage and spot spacing being equal, spot-welded joints in low-strength, very ductile unalloyed titanium sheet were no better in fatigue than similar joints in commercially pure titanium sheet of higher strength.

4. There appears to be no relation between the tension-to-shear ratios determined from tests on single-spot specimens and the fatigue behavior of spot-welded joints in various types of titanium sheet.

5. The fatigue limits of spot-welded joints in unalloyed and alloyed titanium sheet were somewhat lower than for similar joints in stainless steel sheet of equal gage and spot spacing under the same loading conditions. Spot-welded joints in titanium sheet had higher fatigue limits than similar joints in clad 24S-T and clad 75S-T aluminum alloy sheet of the same thickness.

6. Under static tension-shear loading, spot-welded joints in unalloyed and alloyed titanium sheet were stronger than similar joints in Type 321 stainless steel and clad 24S-T and clad 75S-T aluminum alloy sheet of equal thickness.

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RESEARCH NEWS

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of a few plain carbon steels. Today industry is faced not only with the problem of welding all of the ferrous alloys, but also the nonferrous materials, such as aluminum, copper, nickel and their alloys. To develop the techniques and procedures for welding this wide variety of material, a research and development laboratory is required.

It is not only necessary to have a laboratory in which all types of welding can be done and the standard physical tests made to judge the quality of the weldment, but also one in which the metallurgical changes that occur in a material when welded can be evaluated.

In 1945 a field welding department was started by Chicago Bridge & Iron Co. and a laboratory set up at the

(*Continued on page 264-s*)

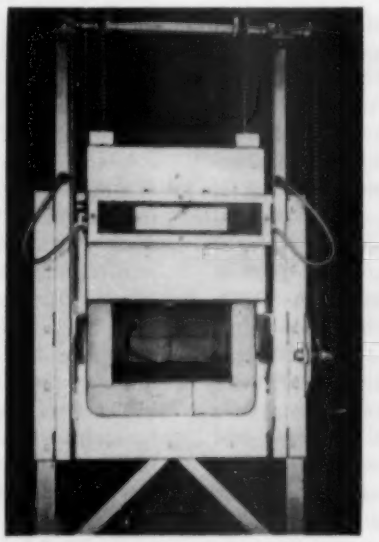

Fig. 3 Electric furnace used for heat treating specimens

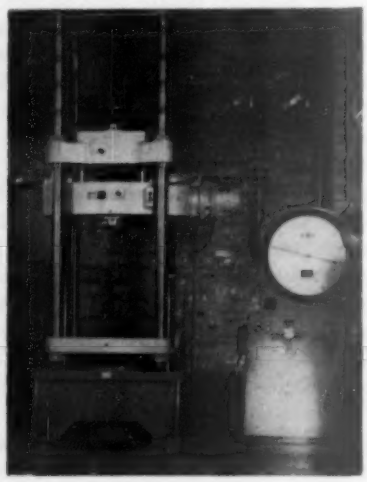

Fig. 4 300,000-lb hydraulic testing machine for pulling welded tensile specimens and applying compression loads to free bend specimens

THE FLASH WELDING OF COMMERCIAL MOLYBDENUM

Part II—Production and testing of flash welds of molybdenum. Optimum values of upset distance assists in eliminating entrapped oxide in arc-cast and sintered molybdenum and reduces carbide precipitation in arc-cast molybdenum. Special consideration is needed for the higher carbon arc-cast molybdenum

BY E. F. NIPPES AND W. H. CHANG

ABSTRACT. Welds of acceptable bend ductility have been produced in commercial molybdenum, both arc-cast and sintered, by flash welding in air. The ductility of these flash welds was impaired by entrapped oxides at the weld interface, the creation of a transverse fiber structure during upsetting, and carbide precipitation in the weld heat-affected zone. Increasing the upset distance to an optimum value assisted in eliminating entrapped oxides in both grades of molybdenum and reduced the severity of carbide precipitation in the arc-cast molybdenum. An increase in the amount of upset beyond the optimum value produced a transverse fiber structure in the weld zone causing severe reduction in bend ductility. Steep temperature gradients at the initiation of upset, produced by high rates of platen acceleration and short clamping distances, were found to localize the carbide precipitation and provide superior bend ductilities in the higher carbon arc-cast molybdenum. No improvement in bend-ductility was obtained with either arc-cast or sintered molybdenum when tank argon or tank hydrogen atmospheres were employed during welding. Flash welds made in arc-cast molybdenum showed the highest bend ductility when made in air, apparently a result of the decarburizing action of the oxygen.

Introduction

This is the second part of an investigation on the flash welding of commercial molybdenum. The object of the investigation was to study the applicability of the flash-welding process to the production of ductile molybdenum welds. Since the temperature-dependent processes of recrystallization and oxidation, which ultimately control the properties of the weld joint, were involved, the investigation was divided into two parts: Part I, temperature distribution during parabolic flashing of $^1/_2$-in. sintered and wrought molybdenum rods and Part II, production and testing of flash welds of molybdenum. The results of Part I have already been presented.[1]

In addition to its flashing action, the flash-welding process is also characterized by the use of upsetting which makes a joint by squeezing out most of the undesirable material near the flashing interface. Such undesirable material usually consists of oxides, porosity, and whatever other inclusions or embrittling phases formed during the flashing period. As a second consequence of upsetting, the resulting weldment structure is plastically deformed. In the case of molybdenum, such deformation is beneficial to the joint in refining its recrystallized zone, reducing the remaining porosity, and breaking up the oxide film supposedly formed around the grain boundaries in the weld.

The amount of upset required to eliminate most of the impurities is closely dependent upon the width of the heat-affected zone which, in turn, is primarily a function of the temperature distribution at the instant of upsetting. The temperature distribution is also of importance in the choice of upsetting conditions in that it determines the plasticity of the heat-affected zone and hence controls the amount of upset possible under a given upsetting force. It is because of these relationships that the planning of the present work, as well as the interpretation of subsequent results, were greatly facilitated by the information obtained in Part I.

Purpose and Scope

The specific purpose of this research lay in the study of the upsetting conditions which affect the bending ductility of flash welds of commercial molybdenum. In view of the vital dependence of the ductility upon the microstructural changes taking place at the elevated temperatures during welding, the primary upsetting conditions investigated in the present study included platen acceleration, amount of upset, and welding atmosphere. The effect of clamping distance was neglected for reasons given later, whereas the effect of specimen dimensions could not be included because of the limited supply of material.

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A simple-beam bending test was used to evaluate the ductility of the flash welds. To facilitate the interpretation of the bending results, the present work was supplemented with a study of the microstructural changes resulting from various upsetting conditions.

Experimental Work

Materials

Most of the present work was conducted on $^1/_4$- x 1- x 8-in. arc-cast molybdenum slabs supplied by the Metallurgy Division of the Oak Ridge National Laboratory. Some limited data were also obtained from two lots of $^1/_2$- x $^1/_4$- x 6-in. sintered molybdenum slabs supplied by one of the leading molybdenum manufacturers. The microstructures of the as-received materials are shown under different magnifications in Fig. 1. The oxygen, carbon and nitrogen contents of these materials were analyzed by the Chemical Laboratory of National Research Corp. as follows:

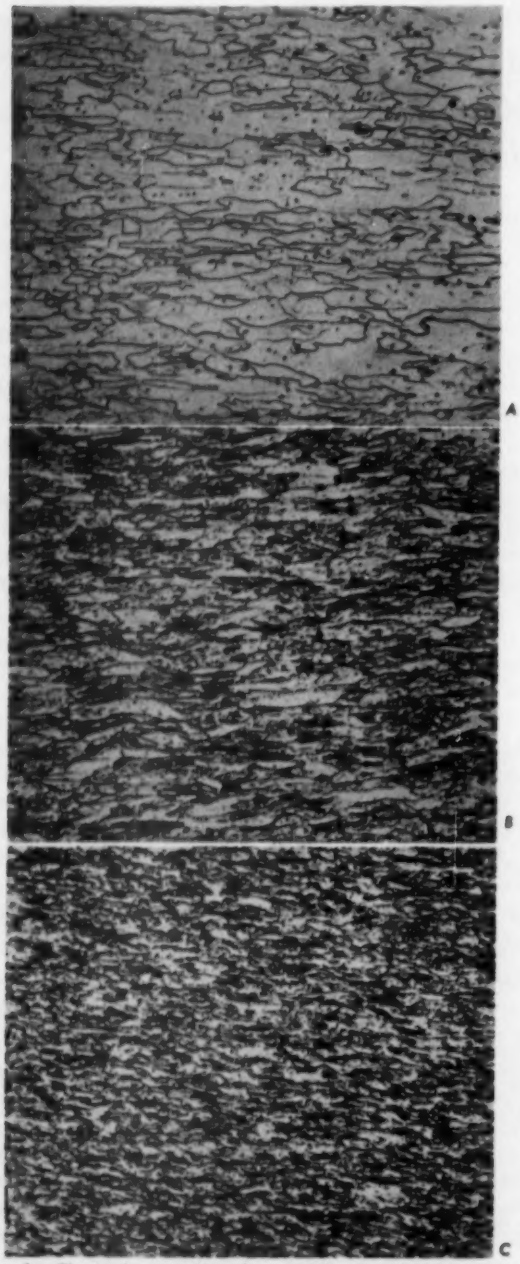


Fig. 1 Photomicrographs of as-received molybdenum

(A) Arc-cast molybdenum; × 50. (B) Sintered molybdenum; lot No. 1; × 200. (C) Sintered molybdenum; lot No. 2. × 200.

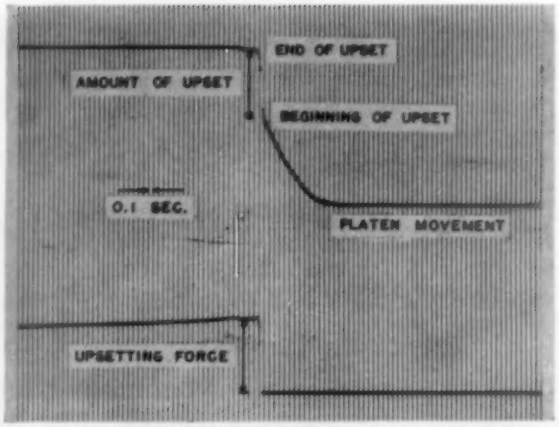


Fig. 2 Photograph of an oscillographic record showing upsetting conditions

Type of molybdenum	*Percent* O_2	*C*	N_2
Arc-cast	0.0005*	0.035	<0.0001*
Sintered, Lot No. 1	0.0005†	0.0049	0.0003†
Sintered, Lot No. 2	0.0007†	0.0041	0.0002†

* Average of two readings.
† Average of three readings.

To facilitate subsequent discussion of the bending results, it is to be noted that in addition to its larger grain size compared with the sintered molybdenum, the arc-cast molybdenum also had carbide particles as a second phase. For the sintered molybdenum, the grain size of Lot no. 2 was finer than that of Lot no. 1. Aside from this, these two lots of sintered molybdenum did not differ significantly either in oxygen, carbon and nitrogen contents or in microstructure. Yet, as will be shown later, there was considerable difference in bending ductility between them in both as-received and welded conditions.

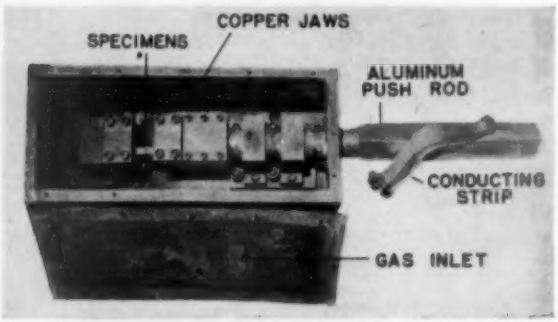


Fig. 3 Photograph of the steel chamber for making flash welds in protective atmospheres

with argon for 15 min. When hydrogen was used, the chamber was flushed first with argon for 15 min and

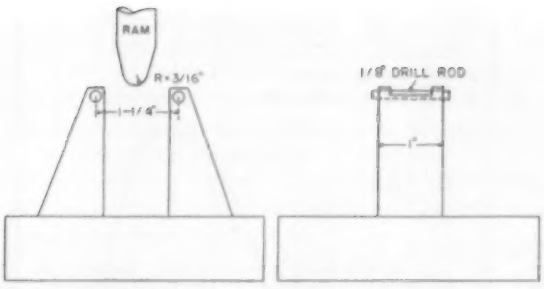


Fig. 4 Sketch of bending jig for testing flash welds

Experimental Procedure

1. Upsetting

Based on the information obtained in Part I,[1] the 1.5-in. clamping distance was chosen in the upsetting operation in order to minimize the width of the recrystallized zone and also to prevent buckling during upsetting. In the flash welding of arc-cast molybdenum, a wide range of platen accelerations (0.006, 0.024, 0.06, 0.09, 0.12, 0.15, 0.20 and 0.26 ips^2) was used. Because the results indicated that better welds were made with higher rates of platen movement, two accelerations, 0.15 and 0.26 ips,^{2} were employed in the welding of sintered molybdenum.

All specimens, $^1/_2$- x $^1/_4$- x 2.6-in. in size, were welded with a parabolic flashing pattern in the same 300-kva Federal Flash Welder used in the study of temperature distribution. The amount of upset and the upsetting force were separately recorded on a multi-channel oscillograph. A typical record is reproduced in Fig. 2 which shows that the rapid upsetting action took place in less than 0.1 sec.

The flash welds were made in both air and undried flowing argon or hydrogen. For the later purpose, a steel chamber, 7- x 7- x 22-in. over-all dimensions, was constructed containing specially-built non-water-cooled copper jaws. Transmission of platen movement was effected by a 2-in. aluminum push rod which passed through a rubber-gasket-lined hole at one end of the chamber. A photograph of the chamber is shown in Fig. 3. In making a weld, the chamber was flushed

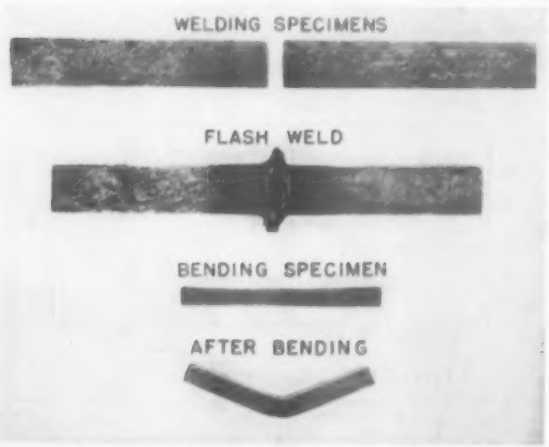


Fig. 5 Photograph showing various stages of preparation and testing of flash welds

Table 1—Welding Conditions and Results of Bend Test on Flash Welds of Arc-Cast Molybdenum

Specimen	Welding atmosphere	Platen* acceleration ips^2	—Upset— Amount in./spec.	Force kips.	—Bending† — Max. load lb.	Angle deg.
BO	As-received base metal without welding					>55
B1-1	air	0.006	0.145	...	510	5
B1-2	air	0.006	0.145	...	555	20
B2-1	air	0.024	0.145	...	310	2
B2-2	air	0.024	0.145	...	460	2
B2-3	argon	0.024	0.165	3.6	565	17
B2-4	argon	0.024	0.165	3.6	565	5
B3-1	air	0.060	0.082	1.6	440	0
B3-2	air	0.060	0.110	1.7	590	26
B3-3	air	0.060	0.125	1.8	630	31
B3-4	air	0.060	0.145	2.1	640	31
B3-5	air	0.060	0.155	...	635	32
B3-6	air	0.060	0.160	...	670	32
B3-7	air	0.060	0.200	3.4	640	19
B4-1	air	0.090	0.078	1.6	350	0
B4-2	air	0.090	0.110	2.0	600	18
B4-3	air	0.090	0.113	2.0	615	17
B4-4	air	0.090	0.130	...	630	27
B4-5	air	0.090	0.130	...	665	30
B4-6	air	0.090	0.137	2.2	715	26
B4-7	air	0.090	0.165	3.0	670	32
B4-8	air	0.090	0.200	3.4	660	30
B5-1	air	0.120	0.078	1.6	500	0
B5-2	air	0.120	0.082	1.7	480	0
B5-3	air	0.120	0.095	1.8	675	18
B5-4	air	0.120	0.110	1.9	650	25
B5-5	air	0.120	0.143	2.5	700	32
B5-6	air	0.120	0.193	3.6	660	26
B5-7	air	0.120	0.200	...	630	12
B6-1	air	0.150	0.125	2.8	680	21
B6-2	air	0.150	0.160	...	680	31
B6-3	air	0.150	0.160	3.5	625	43
B6-4	hydrogen	0.150	0.165	4.2	660	20
B6-5	hydrogen	0.150	0.175	4.8	680	13
B6-6	hydrogen	0.150	0.180	4.8	590	19
B6-7	hydrogen	0.150	0.200	...	560	13
B6-8	air	0.150	0.203	5.2	750	65
B6-9	air	0.150	0.245	6.0	580	7
B6-10	air	0.150	0.247	6.0	680	31
B7-1	air	0.200	0.125	2.5	710	26
B7-2	argon	0.200	0.135	3.4	670	16
B7-3	air	0.200	0.155	3.2	685	35
B7-4	air	0.200	0.155	3.5	765	43
B7-5	argon	0.200	0.165	4.5	700	15
B7-6	air	0.200	0.225	6.0	780	23
B7-7	air	0.200	0.240	6.8	760	11
B7-8	argon	0.200	0.260	7.7	800	17
B8-1	air	0.260	0.120	3.0	660	29
B8-2	air	0.260	0.150	3.3	760	27
B8-3	air	0.260	0.156	3.5	810	25
B8-4	argon	0.260	0.186	5.2	720	14
B8-5	air	0.260	0.220	7.6	815	19
B8-6	argon	0.260	0.220	6.3	640	14
B8-7	hydrogen	0.260	0.240	8.3	720	8
B8-8	air	0.260	0.250	8.3	840	19

* At clamping distance of 1.5 in.

† Bend test conducted at room temperature and at a deflecting rate of about 0.005 ipm.

$^3/_{16}$ (thickness) x $^1/_4$ x 2 in., was supported by two $^1/_8$-in. drill rods inserted into the top of the legs of the

with argon for 15 min. When hydrogen was used, the chamber was flushed first with argon for 15 min and then with hydrogen for 5 min.

2. *Bend Testing of Flash Welds*

From the welds, specimens were milled for a simple-beam bend test. This test was chosen because of its simplicity in evaluating the ductility of brittle materials. As shown in Fig. 4, the bending jig had a span of $1^1/_4$ in. and a ram of $^3/_{16}$ in. radius. The specimen,

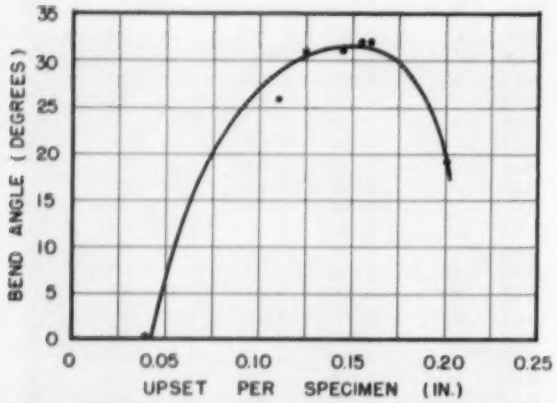


Fig. 6 Effect of upset on bend angle of arc-cast molybdenum flash welds at platen acceleration of 0.060 in./sec.^{2} (all welds made in air)

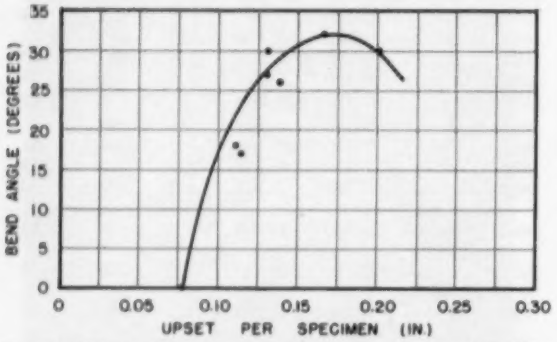


Fig. 7 Effect of upset on bend angle of arc-cast molybdenum flash welds at platen acceleration of 0.090 in./sec.^{2} (all welds made in air)

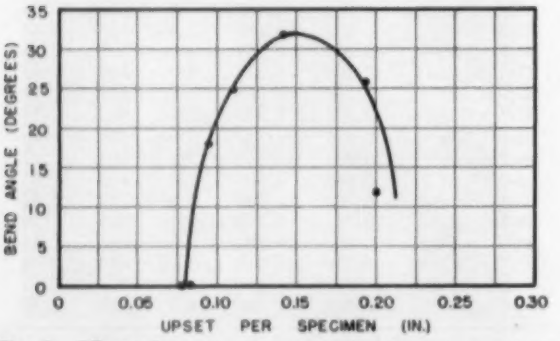


Fig. 8 Effect of upset on bend angle of arc-cast molybdenum flash welds at platen acceleration of 0.120 in./sec.^{2} (all welds made in air)

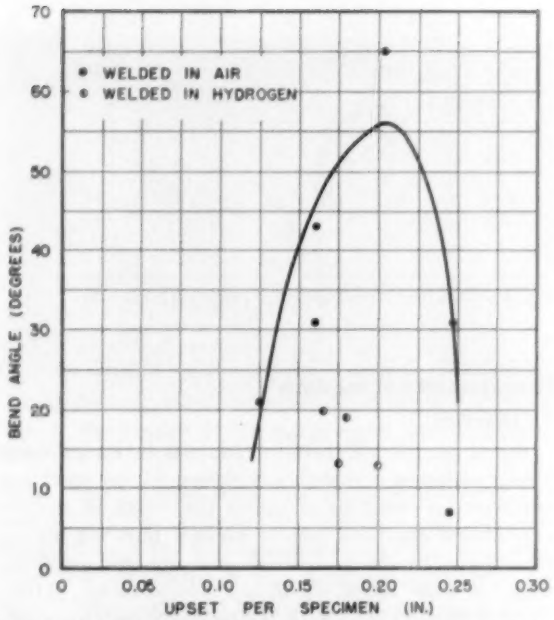


Fig. 9 Effect of upset on bend angle of arc-cast molybdenum flash welds at platen acceleration of 0.150 in./sec.^{2}

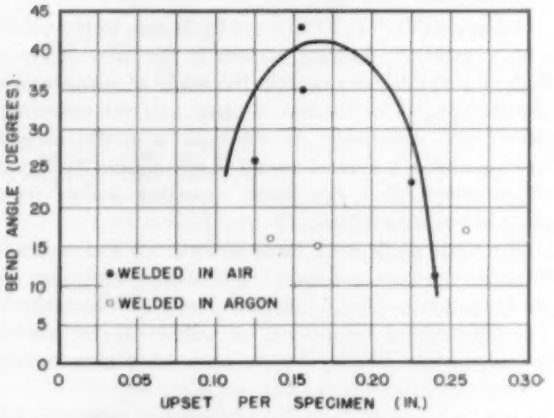


Fig. 10 Effect of upset on bend angle of arc-cast molybdenum flash welds at platen acceleration of 0.200 in./sec.^{2}

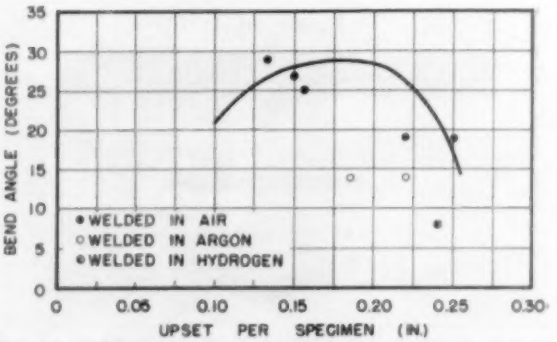


Fig. 11 Effect of upset on bend angle of arc-cast molybdenum flash welds at platen acceleration of 0.260 in./sec.^{2}

$^3/_{16}$ (thickness) x $^1/_4$ x 2 in., was supported by two $^1/_8$-in. drill rods inserted into the top of the legs of the jig. The test was conducted at room temperature in a Baldwin-Southwark universal testing machine, using a deflection rate of about 0.005 ipm which was equivalent to a maximum strain rate of 10^{-5} per sec. in the outermost fiber of the specimen. A photograph showing the welding specimens in various stages of preparation and testing is presented in Fig. 5.

3. *Microscopic Examination of Flash Welds*

In order to study the structural changes occurring in the specimens during welding, additional welds were made for microscopic observations. All metallographic specimens, unless otherwise stated, were manually polished and etched with Murakami's reagent.

Data, Results, and Discussion

1. *Arc-Cast Molybdenum Flash Welds Made in Air*

The welding conditions and results of bend test of the arc-cast molybdenum flash welds made in air are presented in Table 1. From this table the bend angle of the welds is plotted in Figs. 6, 7, 8, 9, 10 and 11 as a function of the amount of upset for each of the platen accelerations. For comparison purposes, the individual curves are summarized in Fig. 12. It is seen that these graphs may be divided into three regions. In the first region with upset less than 0.1 in./specimen, all

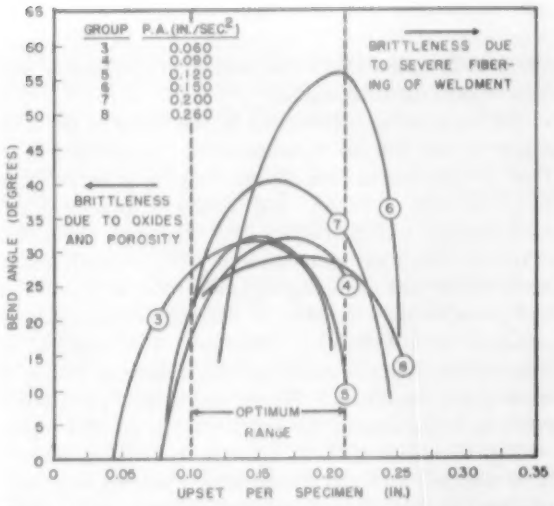
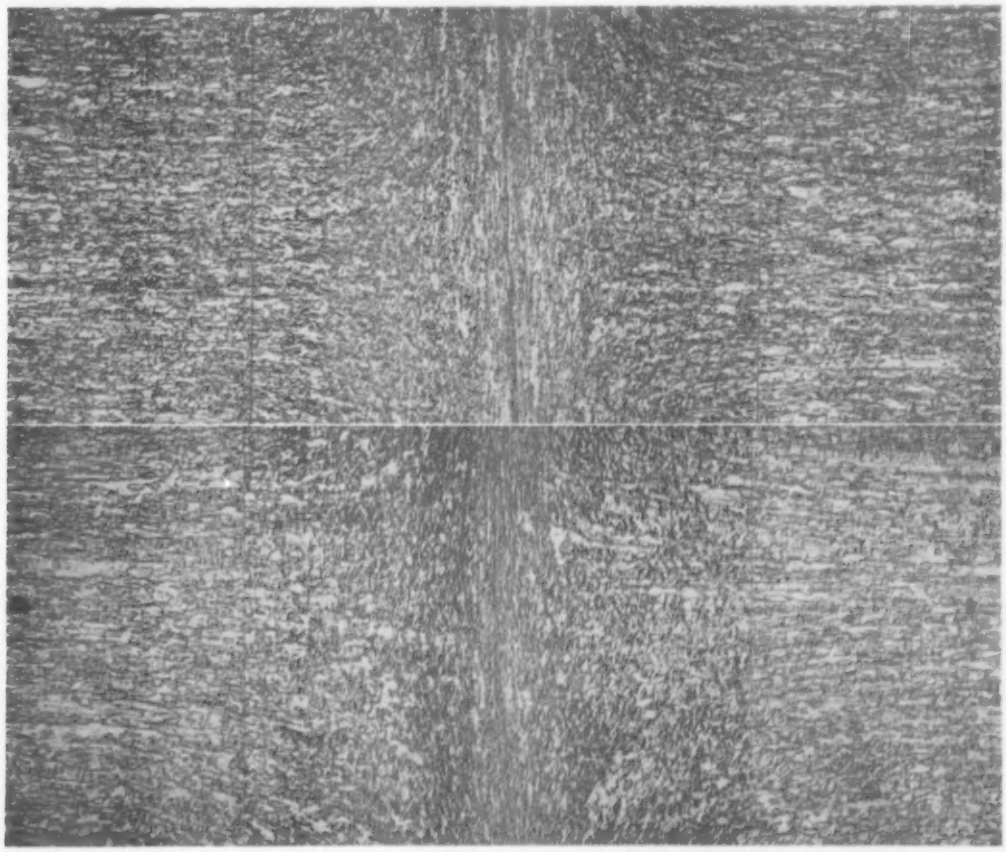


Fig. 12 Summary curves showing effect of upsetting conditions on bend angle of arc-cast molybdenum flash welds (all welds made in air)

the welds were brittle (bend angle below 20°) irrespective of platen acceleration. Considerable ductility was observed (20 to 65°) in the second region which included the welds upset within the range of 0.1 to 0.21 in./specimen. These welds compare rather favor-



(A) Specimen B7-9; platen acceleration, 0.20 in./sec^2; amount of upset; 0.12 in./specimen.

(B) Specimen B7-10; platen acceleration, 0.20 in./sec^2; amount of upset, 0.19 in./specimen.

Fig. 13 Photomicrographs showing effect of amount of upset on microstructure of arc-cast molybdenum flash welds. × 20

ably in ductility with those made by other conventional processes. However, in the third region of still larger amounts of upset, the welds tended to exhibit low and inconsistent ductility again.

The cause of embrittlement in the welds of the first region is not difficult to understand. As explained in Part I,[1] the region behind the flashing interface was recrystallized, oxidized, and rendered porous when molybdenum was flashed in air. Although the width of the recrystallized zone was shown to vary with platen acceleration and clamping distance, most of the oxides and porosity were confined to the section immediately adjacent to the flashing interface. The removal of this section depends solely on the squeezing action of subsequent upsetting. When the upset was insufficient, as in the case of the welds lying in the first region of Fig. 12, some of these massive embrittling sources were trapped within the weld zone, resulting in a joint of very low ductility. Furthermore, some of the brittleness was also contributed by the preferentially precipitated carbides. As will be explained later, some of the carbides near the flashing interface were dissolved during flashing and reprecipitated along grain boundaries after upsetting. At small amounts of upset, the cooling rate of the specimen was slow because of the relatively long remaining heat-flow path. Such a condition favored the carbide precipitation and consequently further reduced the ductility of the welds made with insufficient amount of upset.

In addition to its cleaning function, upsetting also deformed the weld center into a fibered structure, more or less perpendicular to that of the wrought base metal, as shown in Fig. 13. For a given platen acceleration and clamping distance, the extent of plastic working obviously increased with the amount of upset. As a result, a specimen welded at a certain amount of upset would have a wider, finer and more perfectly oriented fiber structure, and a narrower recrystallized zone than one welded at a smaller amount of upset. This effect is also illustrated in Fig. 13 which shows the microstructures of specimens B7-9 and B7-10, welded at the same platen acceleration of 0.20 ips^2 with upsets of 0.12 and 0.19 in./specimen, respectively. It is to be noted that, since the limited plasticity of molybdenum did not permit sufficient upset to remove completely the recrystallized zone farther away from the interface, some oxide still remained in the weldment. In the present investigation, the microscopic examination did not definitely establish the presence of such oxide in a properly upset weld. However, should an oxide be present as a submicroscopic film around the grain boundaries, it would have been broken up by the upsetting.

From the preceding reasoning, it would seem to follow that, once the most harmful zone near the flashing interface is squeezed out, the ductility of the flash welds should increase with increasing amount of upset, until the maximum upset permitted by the plasticity of molybdenum under the prevailing conditions is reached. Actually, the situation was more complicated. At the

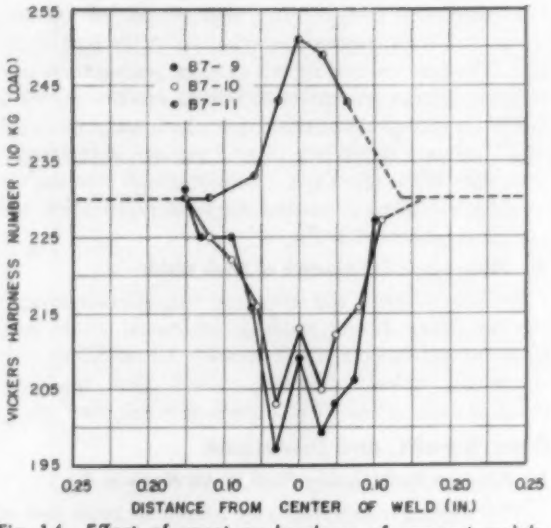


Fig. 14 Effect of upset on hardness of arc-cast molybdenum flash welds

Platen acceleration, 0.20 in./sec.^{2}; clamping distance 1.5 in. Amount of upset per specimen B7-9, 0.12 in; B7-10, 0.19 in; B7-11, 0.24 in; Vhn of base metal, 230.

lower range of the second region in Fig. 12, such a relationship held true. However, when the upset exceeded a certain amount, about 0.21 in./specimen in the present case, the fibering of the weld center became extremely severe. The subsequent bend test was in effect applied to a "transverse" specimen with the bending stresses acting practically normal to the "planes of weakness." Little ductility is therefore to be expected in such welds, as evidenced by the rapid drop of bend angles with upset in the third region of Fig. 12.

The effect of upset was also demonstrated by hardness surveys. Figure 14 shows the Vickers hardness surveys of specimens B7-9, B7-10 and B7-11. The latter was also welded at the same platen acceleration of 0.20 ips^2 but at a still larger amount of upset of 0.24 in./specimen. Starting from the base metal and traversing toward the weld center, it is seen that softening took place wherever recrystallization occurred during the flashing period. This softening was subsequently counterbalanced by the plastic working of upsetting, as indicated by the fact that the more the upset, the less was the drop in hardness of the recrystallized zone, compared with the base metal. In the case of excessive upset, such as that experienced by B7-11, the plastic deformation was so drastic and far-reaching that its strengthening effect completely overwhelmed the softening, causing an increase in hardness over the entire heat-affected zone. At the center where the deformation was most severe, the hardness reached a peak which was higher the larger the amount of upset.

The comparatively high ductility of the welds included in the second region of Fig. 12 is thus obvious. These welds were relatively clean of oxides and porosity and yet did not suffer undue deformation. However, Fig. 12 indicates that, in this region, considerable differ-

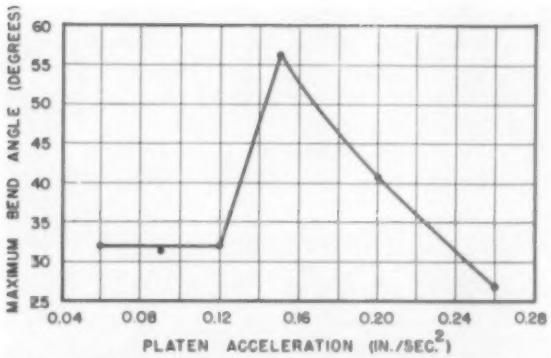
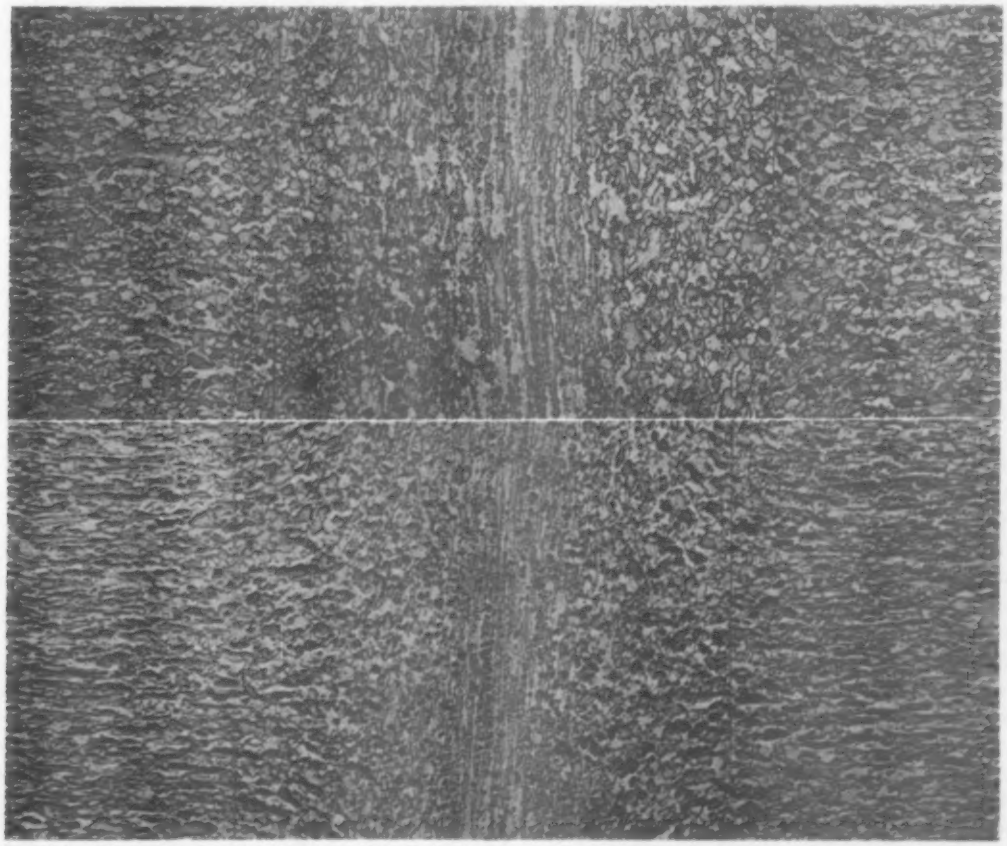


Fig. 15 Effect of platen accelerations on bend ductility of arc-cast molybdenum flash welds

ence in bend ductility existed among the welds made under different platen accelerations. By taking the maximum bend angle of each group as representative, the effect of platen acceleration can be better illustrated in the manner shown in Fig. 15. At low platen accelerations and indeed throughout the range of 0.06 to 0.12 ips,^{2} the maximum bend ductility was low and remained at approximately the same level of about 32°. The bend angle reached a maximum of 56° at the platen acceleration of 0.15 ips,^{2} and dropped rapidly with further increase in platen accelerations.

Before interpreting these results, it is perhaps worthwhile to recapitulate the information obtained in Part I[1] concerning the effect of platen acceleration on the temperature distribution of molybdenum during parabolic flashing. It was found that the steepness of temperature gradient in the region behind the flashing interface increased with increasing platen accelerations. Accordingly, the lower the acceleration the wider would be the recrystallized zone and the higher the stabilized temperature at a point a given distance from the flashing interface. These effects of platen movement during flashing, were evident after upsetting. In Fig. 16 are shown the microstructures of specimens B2-5 and B3-8, welded at the same amount of upset of 0.15 in./specimen with platen accelerations of 0.024 and 0.060 ips,^{2} respectively. In addition to its wider zone of recrystallization, specimen B2-5 appears to have undergone less deformation in the joint than B3-8 for the same amount of upset. This indicates that as a consequence of the higher temperatures induced by the lower platen acceleration, partial recrystallization of the fibered structure had proceeded to a larger extent in B2-5 than B3-8.

Taking into account the difference in exposure associated with different platen accelerations, the implication was clear that specimens flashed under lower platen accelerations would suffer more oxidation. This difference in oxidation is considered primarily respon-



(A) Specimen B2-5; platen acceleration, 0.024 in./sec^2; amount of upset, 0.15 in./specimen.

(B) Specimen B3-8; platen acceleration, 0.060 in./sec^2; amount of upset, 0.15 in./specimen.

Fig. 16 Photomicrographs showing effect of platen acceleration on microstructure of arc-cast molybdenum flash welds. × 20

sible for the variations in ductility, observed in the second region of Fig. 12, of the welds made under different platen accelerations. Superimposed on this oxidation effect was the embrittlement caused by the precipitation of carbides in the weld zone. Such precipitation occurred to a larger extent in the case of lower platen accelerations for reasons given later.

In addition to its relatively low value, the maximum bend ductility, as shown in Fig. 15, remained at about the same level throughout the low range of platen accelerations. No satisfactory explanation has yet been found for this apparently anomalous phenomenon.

While oxidation is considered the fundamental cause of embrittlement at low platen accelerations, the reason for the drop in ductility at platen accelerations higher than 0.15 ips^2 must be sought elsewhere. Apparently, the effect of plastic deformation predominated in this case. The specimens flashed under such high accelerations were characterized by a steep temperature gradient and a narrow recrystallized zone. After the removal of 0.1 to 0.2 in./specimen by upsetting, the remaining adjacent region was relatively low in temperature and therefore limited in plasticity. The impact of the upsetting would then result in a fine and severely fibered structure. As indicated previously, such a structure could not survive much bending without fracture.

It is thus clear that 0.15 ips^2 was the optimum platen acceleration under the given conditions. Both the optimum acceleration and the optimum amount of upset discussed above, are expected to vary with such factors as clamping-jaw geometry, specimen size and shape, clamping distance, etc., which influence the temperature distribution. Nevertheless, the results reported here brought to light the importance of platen acceleration as well as the merits and limitations of upsetting. When both are properly chosen, the characteristics of flash welding, i.e., rapid action and capability of applying force in making a joint, can be utilized advantageously in producing molybdenum welds with acceptable ductility.

On the other hand, it is hardly necessary to point out that flash welding is far from being an ideal means for joining molybdenum. It imposes limitations to the size and shape of specimens that can be welded. Much more important than this, however, is the fact that even the most ductile welds, reported in Table 1, were inferior in ductility to the base wrought metal. There is little doubt that this loss of ductility was, in the main, a consequence of the oxide remaining in the weldment and the unfavorable orientation of the fibered weld zone which provided planes of weakness leading to fracture in subsequent bending. In addition to these two factors, the effect of carbide precipitation also merits consideration.

It was previously mentioned that carbide particles of appreciable size were seen throughout the matrix of the as-received arc-cast molybdenum. The as-polished microstructure of an arc-cast molybdenum flash weld is shown in Fig. 17. The distribution of carbides was

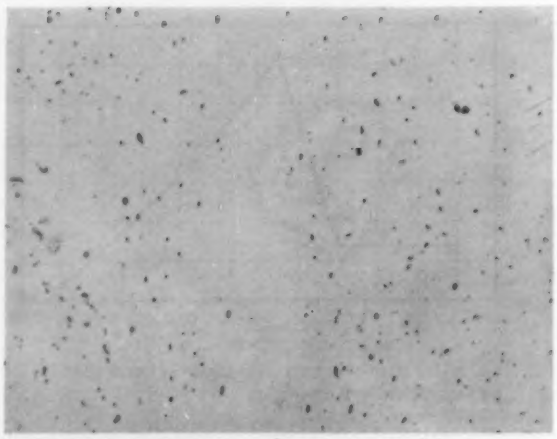


Fig. 17 Photomicrograph of typical as-polished arc-cast molybdenum flash welds showing change of carbide distribution in weld zone. × 100, electrolytic polish

obviously altered in the weld zone which, under low magnification, appeared as an area free of carbides, the width of this area being wider the lower the platen acceleration and the smaller the amount of upset. However, when examined under high magnification, a significant microstructural difference was observed in this area among welds made under different conditions. This is illustrated in Fig. 18 in which the weld centers of three specimens are represented at 1000 ×. The weld zone of B7-10, made with a platen acceleration of 0.20 ips^2 and an upset of 0.19 in./specimen appeared to be clean and consisted of a deformed matrix only. In contrast to this, a second phase, in the form of small, light-etched particles, was found to be present, mainly along grain boundaries but also within the grains, in the weld center of specimen B7-9 which was produced under the same platen acceleration but at a smaller amount of upset (0.12 in./specimen). Under lower platen accelerations, such particles were found to occur to a larger extent, as is evidenced by the weld zone of specimen B3-8 (platen acceleration 0.060 ips^2 and upset 0.15 in./specimen) shown in Fig. 18-C. In all cases, there was no variation in the distribution of these particles along the weld interface, as would have been if these particles had been oxides. This, coupled with the appearance of these particles, led to the belief that they were re-precipitated carbides. The situation is speculated as follows. During flashing, part of the carbides in the region near the interface was oxidized away while the remainder was dissolved by the matrix. The width of the region undergoing such changes was a decreasing function of the platen acceleration but an increasing function of clamping distance, as necessitated by the effects of these two factors upon the temperature gradient. After upsetting, cooling took place in the weld zone. Since the solubility of carbon in the matrix was diminishing, the excess carbon tended to separate as carbides during cooling. Opposing this separation, however, was the rapid cooling rate. It was because of the latter that the carbides occurred as small particles and preferentially along the grain bound-

molybdenum flash welds. While the deformation ex-

center could be the cause of the additional deleterious

aries. Since the cooling rate was slower with gentle temperature gradients, the precipitation proceeded to a larger extent at lower platen accelerations. For a given acceleration, the cooling rate was of course dictated by the final clamping distance after upsetting. The carbide precipitation could not therefore occur to an appreciable extent when the amount of upset was large. It is to be noted that the apparently clean weld zone of a specimen, such as B7-10 shown in Fig. 18-A, should not be taken as an absolute criterion for the absence of minute amounts of carbide precipitation in view of the limited resolving power of an optical microscope.

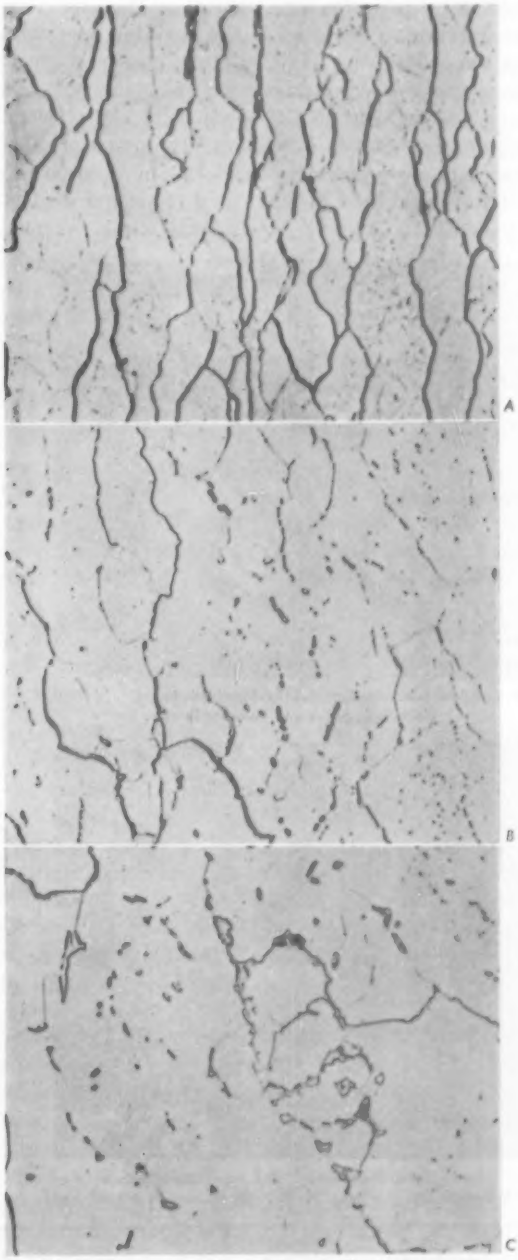


Fig. 18 Photomicrographs of heat-affected zone in arc-cast molybdenum flash welds showing effect of upset conditions on precipitation of carbides. × 1000, hand polish, Murakami's etch

(A) Specimen B7-10; platen acceleration, 0.20 in./sec^2; amount of upset, 0.19 in./specimen. (B) Specimen B7-9; platen acceleration, 0.20 in./sec^2; amount of upset, 0.12 in./specimen. (C) Specimen B3-8; platen acceleration, 0.06 in./sec^2; amount of upset, 0.15 in./specimen.

The grain-boundary precipitation suggested that these carbides were capable of causing embrittlement in the arc-cast molybdenum flash welds. This was supported by the fact, to be described in the following section, that the welds made in argon or hydrogen, which experienced a greater extent of carbide precipitation, were not as ductile as those made in air. In view of the same fact, it is felt that the problem of embrittlement by carbide precipitation may be quite acute and further emphasizes the importance of proper selection of upsetting conditions in flash welding of arc-cast molybdenum.

2. *Arc-Cast Molybdenum Flash Welds Made in Argon or Hydrogen*

The bend test results of the arc-cast molybdenum flash welds made in flowing undried argon or hydrogen are also included in Table 1 and Figs. 9, 10 and 11. By comparing these welds with those made in air, two important differences are outstanding. In the first place, the bend ductility of the welds made in the special atmospheres was considerably lower than that of the welds made in air under similar platen accelerations and amount of upset. For instance, whereas specimens B6-3, B6-8, and B7-4, all welded in air, fractured at angles of 43, 65 and 43°, respectively, the bend angles of specimens B6-4, B6-7 and B7-5, made in argon or hydrogen under similar conditions, were correspondingly, 20, 13 and 15°. In the second place, the bend ductility of the welds made in the special atmospheres fell within the range of 10 to 20°, in spite of the large variations in platen acceleration and amount of upset. In contrast, it was shown that these two upset variables exerted definite influence on the ductility of the arc-cast molybdenum flash welds made in air.

At the first glance, the results on the welds made in the supposedly protective atmospheres seem incompatible with what would normally be expected. The difficulty in interpreting these results does not arise so much from the low ductility itself as from the fact that the ductility was inferior to that of the welds made in air. A survey of the literature[2,3] indicated that molybdenum welds made by other processes in dried helium and hydrogen, were very brittle, presumably because of the minute amounts of oxygen which still remained in the gases. This embrittlement by oxidation undoubtedly was partly responsible for the low ductility of the welds in the present case, since the latter were produced in cylinder argon and hydrogen. However, the same explanation cannot be applied to account for the additional loss of ductility without risking the implication that the undried gases were more oxidizing than air.

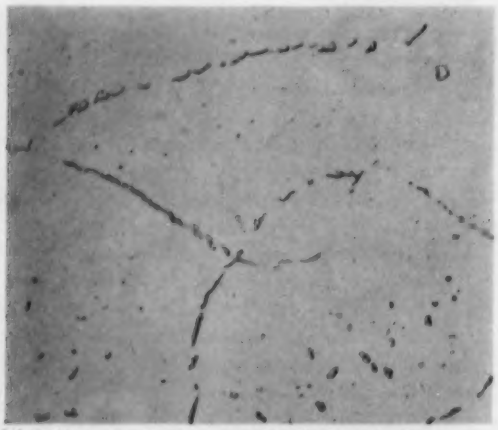
It was stated in the preceding section that weldment fibering was another factor limiting the ductility of

viously been used in preparing the flash welds made in

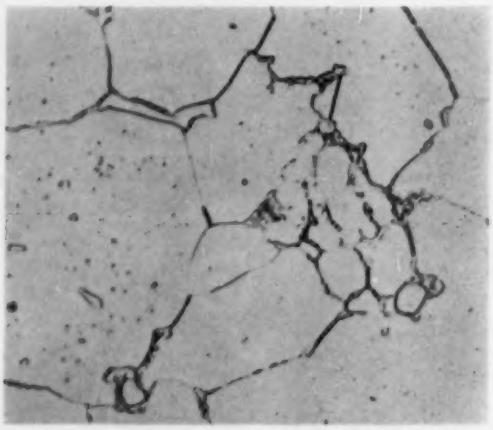
to the weld joint, both grain coarsening and porosity

molybdenum flash welds. While the deformation exerted by a given upsetting is independent of the welding atmosphere, it may change as a consequence of any variation in the manner of upsetting. In this respect, the use of the specially-built jaws for welding in the chamber might encourage suspicion. However, visual inspection of the weld joints showed that specimen-alignment was better in the special jaws than in those used for welding in air, a fact in favor of improved ductility in the welds made in the chamber. Another difference between the two sets of clamping jaws was the cooling rate, arising from the difference in jaw dimensions as well as in the use of coolant. Although the extent of fibering induced by a given amount of upset might thus be varied, it is unlikely that the variations so induced in plastic deformation of the weld center could be the cause of the additional deleterious effect on the ductility of the welds under discussion, as evidenced by the fact that the ductility was insensitive to the wide changes of amount of upset.

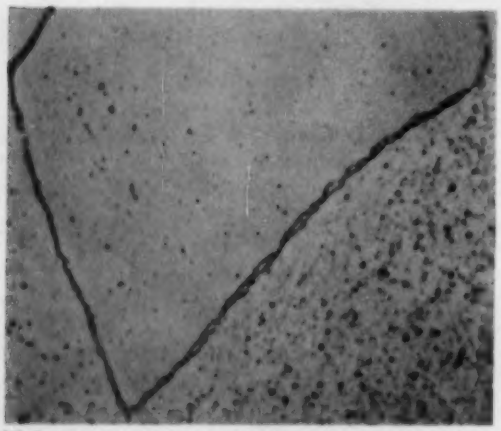
By eliminating oxidation and weldment fibering as being responsible for the observed results, the foregoing arguments point indirectly to the possibility of some harmful microstructural changes resulting from welding. Up to this time, the information on carbide precipitation as described in the preceding section had not been obtained. The first clue to this problem was discovered by electrolytically polishing the weld specimens. The Coons' No. 2 solution for electrolytically polishing arc-cast molybdenum,[4] composed of 50 ml. concentrated hydrochloric acid, 20 ml. concentrated sulphuric acid, and 150 ml. methyl alcohol, had pre-



(A) Carbide precipitation at grain boundaries and within grains. ×1000. Hand polish and Murakami's etch.



(B) Carbide concentration due to localized fusion. ×1000. Electrolytic polish and Murakami's etch.



(C) Grain coarsening and network of carbides. ×1000. Electrolytic polish and Murakami's etch.

(D) Extreme case of porosity. Also shows grain boundary attack by polishing solution. ×100. As electrolytically polished.

Fig.	Specimen	Welding Atm.	Platen Acceleration, in./sec.^{2}	Amount of Upset, in./specimen
A	BB-9	Hydrogen	0.260	0.16
B	BB-9	Hydrogen	0.260	0.16
C	BX-1	Argon	0.010	0.14
D	BB-9	Hydrogen	0.260	0.16

Fig. 19 Photomicrographs showing microstructural changes in heat-affected zone of arc-cast molybdenum flash welds made in protective atmospheres

made either fast enough to suppress the precipitation or

As shown previously, the two lots of sintered molyb-

viously been used in preparing the flash welds made in air. As shown in Fig. 17, the etchant attacked neither the massive carbides in the base metal nor the weld center which, in this case, was relatively clean due to a considerable amount of upset (0.24 in./specimen). However, when the same solution was used on the welds made in argon and hydrogen, the heat-affected zone often suffered severe etching along the grain boundaries, indicating that something at these locations had been dissolved by the solution. Such specimens had to be manually polished to retain the original structure. On examining the properly prepared specimens, either electrolytically or manually polished, a second phase was found in the heat-affected zone. This phase had the same form, appearance, and distribution as described in the preceding section. For the reasons previously given, together with the absence in the special atmospheres of any element capable of causing so much contamination, this phase was identified as reprecipitated carbide. In some instance, localized fusion had also taken place, resulting in carbide concentration at the grain boundaries. These microstructural changes are shown in Fig. 19.

The mechanism of carbide precipitation was of course the same as that described for the flash welds made in air. However, the precipitation was more extensive in the welds made in argon and hydrogen. The latter atmospheres being less oxidizing than air, removed less carbon from the weld joint. Subsequent cooling therefore forced more carbon to separate. Furthermore, the precipitation was also facilitated by the slower cooling rate of the special jaws which were not water-cooled and were smaller than those used for welding in air.

In addition to carbide precipitation, grain coarsening and porosity were also found in the heat-affected zone of the welds made in the protective atmospheres under abnormal conditions. For example, grain coarsening, as shown in Fig. 19-C, was particularly noticeable in the welds made with low platen accelerations which, combined with the slow cooling effect of the special jaws, shifted the dynamic thermal equilibrium during flashing toward higher temperatures, in accordance with the analysis presented in Part I.[1] Under these circumstances which favored carbide precipitation by slow cooling but limited the amount of surface to accommodate the precipitate by grain coarsening, the carbide tended to form a continuous network around the matrix grains, as is evidenced in Fig. 19-C. Porosity, on the other hand, was serious only when the amount of upset was insufficient. An extreme example of this is illustrated in Fig. 19-D. It is apparent that such porosity was a result of mechanical entrapment of the flowing gases. It should be pointed out that the examples shown in Figs. 19-C and 19-D were the worst cases observed and are presented here to illustrate the damage that improper welding conditions can do to the weld joint. Whenever sufficient amounts of upset were used to remove enough heat-affected material near the interface and to impart sufficient deformation to the weld joint, both grain coarsening and porosity were far less serious than the cases depicted above.

Summarizing the findings, the welds made in argon or hydrogen experienced, under normal upsetting conditions, more extensive carbide precipitation and a slightly larger degree of grain coarsening and porosity than those welds made in air. The embrittling effect of the carbide precipitation along grain boundaries was previously discussed and was believed to increase with increasing extent of the preferential precipitation. Grain coarsening in metals and alloys is, in general, associated with reduction in ductility, and is particularly so in the presence of an embrittling precipitated network. Similarly, a decrease in ductility is to be expected whenever porosity occurs in the weld joint. It seems reasonable, therefore, to conclude that as a result of these microstructural changes, the ductility of the welds made in argon or hydrogen fell below that of the welds made in air. Of these three microstructural changes it appears that the major part of the embrittlement came from the precipitated carbides for several reasons. Firstly, it was mentioned that, regardless of platen acceleration and amount of upset, all welds made in the special atmospheres fractured within the range of 10 to 20° bend angle. This indicates that, in the present case, grain coarsening and porosity, the extent of which was determined by these upsetting conditions, were not serious in properly made welds. Their embrittling effect, whatever it may be, was overshadowed by the effect of a third source possessing a greater potency of embrittlement. From previous discussions, this third effect most probably came from carbide precipitation. This being so, the ductility of the welds would then be affected more by the relatively low oxidizing power of the protective atmospheres and the mild cooling effect of the special clamping jaws than by the other two upsetting conditions. Secondly, an arc-cast molybdenum flash weld made in the steel chamber in the presence of air (with the top open) with a platen acceleration of 0.15 ips^2 and an upset of 0.16 in./specimen, exhibited a bend angle of 33°. The latter was of the same magnitude as the bend angle of its equivalent (specimen B6-2, Table 1) made in air. Since such a high value of bend angle had not been attained by any of the welds made in argon or hydrogen, it may be construed as a result of a lesser amount of carbide separation in this particular weld. Furthermore, this relatively high bend angle eliminated the possibility that the additional loss of ductility of the welds made in the special atmospheres could be caused by some hidden mechanical or electrical defect of the chamber. Lastly, the most convincing evidence in favor of the embrittlement by carbide precipitation came from the fact, to be discussed more fully in the next section, that in flash welding of sintered molybdenum which did not contain carbides as a second phase, the welds made in argon or hydrogen were, in general, as ductile as those made in air.

In view of the damaging effect of carbide precipitation, it follows that, unless the cooling rate can be

hand, when the upset distance was approximately 0.15

It is definitely clear that the ductility of molybdenum flash welds is critically influenced by platen accelera-

made either fast enough to suppress the precipitation or slow enough to permit the separation of massive, less harmful carbides, the use of a protective atmosphere or vacuum will not necessarily lead to improved ductility in flash welds of commercial arc-cast molybdenum. When a slow cooling rate is used, the effect of prolonged oxidation by a contaminating atmosphere must be taken into consideration.

3. *Sintered Molybdenum Flash Welds*

The original planning of this part of the investigation called for the flash welding of arc-cast molybdenum alone. However, toward the end of the program, it was deemed desirable to conduct a small-scale study on sintered molybdenum for some general information, as well as to confirm indirectly the effect of carbide precipitation in the arc-cast molybdenum flash welds. The welding conditions and the bend-test results are given in Table 2 in which the welds made of Lot no. 1 are designated as Series C and those of Lot no. 2 as Series D. Since the data are rather limited, the discussion will of necessity be confined to generalities except where definite conclusions are obvious.

Table 2—Welding Conditions and Results of Bend Test on Flash Welds of Sintered Molybdenum

Specimen	Welding atmosphere	Platen* acceleration ips²	—Upset— Amount in./spec.	Force kips.	—Bending†— Max. load lb.	Angle deg.
CO-1‡	As-received base metal without welding					90
CO-2	As-received base metal without welding					70
DO-1§	As-received base metal without welding					30
DO-2	As-received base metal without welding					5
C6-1	air	0.150	0.130	2	580	37
C6-2	air	0.150	0.155	3	630	21
C6-3	air	0.150	0.165	4.3	600	2
C6-4	air	0.150	0.185	5	710	12
D6-1	air	0.150	0.135	2	400	0
D6-2	air	0.150	0.170	3	535	1
C8-1	air	0.260	0.090	2	610	36
C8-2	air	0.260	0.120	3	625	46
C8-3	air	0.260	0.150	3	670	10
C8-4	hydrogen	0.260	0.087	2.5	600	27
C8-5	hydrogen	0.260	0.087	2.5	740	62
C8-6	argon	0.260	0.110	3	630	22
C8-7	hydrogen	0.260	0.110	3	730	35
C8-8	hydrogen	0.260	0.135	5	870	65
C8-9	hydrogen	0.260	0.145	5	600	2
D8-1	air	0.260	0.095	2	550	3
D8-2	air	0.260	0.095	2	550	0
D8-3	air	0.260	0.120	3	660	>37
D8-4	air	0.260	0.150	3	480	0
D8-5	hydrogen	0.260	0.087	2.5	560	6
D8-6	hydrogen	0.260	0.087	2.5	615	7
D8-7	argon	0.260	0.110	4.5	600	0
D8-8	argon	0.260	0.110	3	570	0
D8-9	hydrogen	0.260	0.110	3	545	3
D8-10	hydrogen	0.260	0.145	5	575	0
D8-11	hydrogen	0.260	0.145	4	615	0

* At clamping distance of 1.5 in.

† Bend test conducted at room temperature and at deflecting rates of 0.010 ipm for the base metals and 0.005 ipm for the welds.

‡ Welds made of Lot no. 1 sintered molybdenum are designated as Series C.

§ Welds made of Lot no. 2 sintered molybdenum are designated as Series D.

As shown previously, the two lots of sintered molybdenum had essentially identical analysis in oxygen, carbon and nitrogen. Their microstructures were also similar except that Lot no. 1 had a larger grain size than Lot no. 2, both lots being finer grained than the arc-cast molybdenum. Based on these considerations alone, substantial difference in ductility between these two lots of molybdenum would probably not be suspected. An inspection of Table 2, however, reveals immediately that the welds made of Lot no. 2 were much more brittle than those made of Lot no. 1. Of the welds made of Lot no. 2, only one specimen, D8-3, welded in air with a platen acceleration of 0.26 ips² and an upset of 0.12 in./specimen, showed satisfactory ductility. All of the other welds from this lot had extremely low bend angles (0 to 7°), regardless of welding atmosphere, platen acceleration, and amount of upset. In decided contrast to this the welds made from Lot no. 1 molybdenum exhibited considerably higher ductility, whether made in air, argon or hydrogen. Furthermore, such a substantial difference in ductility was also shown by the base metals. Two bend specimens were made of each lot of the as-received sintered molybdenum and tested at a deflecting rate of approximately 0.010 ipm. The specimens made of Lot no. 1 fractured at 90 and 70° whereas those of Lot no. 2 fractured at 30 and 5°. This strongly suggests that the difference in weldment ductility between these two lots very probably arose from the corresponding base metals. A possible explanation lies in the amount of work received by these base metals. It is known that, in order to be ductile, commercial molybdenum has to be cold worked to a fiber structure, presumably to break up the submicroscopic oxide films. On the other hand, it is also known that for metals in general, ductility decreases with the amount of cold work. It is entirely possible, therefore, that for molybdenum, there is an optimum amount of cold work beyond which the embrittling effect of the cold work predominates. The severely fibered structure of Lot no. 2 sintered molybdenum slabs may well fall in this category.

In what follows the discussion will be confined to the flash welds made of Lot no. 1 sintered molybdenum. In the case of welding in air, it is seen that these sintered molybdenum flash welds had bend ductility comparable to that of the arc-cast molybdenum welds. The relationships between weld ductility and upsetting conditions differed in some aspects, however. For instance, as shown previously in Fig. 12, in the lower region of amount of upset (about 0.1 in./specimen), the arc-cast molybdenum flash welds were brittle (less than 20 deg. bend angle) because of entrapped oxides and relatively extensive carbide precipitation. Since such precipitation was not present in sintered molybdenum welds, the latter would be expected to show better ductility in this range of upset, compared with the arc-cast molybdenum flash welds. That this is so can be confirmed from the fact that specimen C8-1 and C8-2, made of Lot no. 1 in this range of upset, had bend angles of 36 and 46°, respectively. On the other

either essential or desirable. Inasmuch as the ductility

duce a transverse fiber structure in the weld zone caus-

hand, when the upset distance was approximately 0.15 in./specimen or greater, the sintered molybdenum welds were relatively brittle. As shown in Fig. 12, this represented the range of upset for maximum ductility for arc-cast molybdenum. In other words, the sintered molybdenum flash welds appeared to be more susceptible to embrittlement by fibering at the weld center line. Because of the limited amount of data, it can only be stated that such a susceptibility was related to the original grain structure as well as the composition of the base metals.

A third difference in ductility between the arc-cast molybdenum flash welds and Lot no. 1 sintered molybdenum flash welds with respect to upsetting conditions lay in platen accelerations. It was shown in Fig. 15 that in the flash welding of arc-cast molybdenum, 0.15 ips^2 was found to be the optimum platen acceleration. In the case of the sintered molybdenum, only two accelerations, 0.15 ips^2 and 0.26 ips,^{2} were used. It appeared that better ductility was associated with the welds made with the higher platen acceleration. This probably has no significance other than that less oxidation, or shorter exposure at high temperatures, was more important in flash welding of the sintered molybdenum.

The most important observation obtained in the flash welding of the Lot no. 1 sintered molybdenum was the effect of argon or hydrogen atmosphere. Improvement in weld ductility by welding in these gases was not expected since the latter were by no means pure enough to be free from contaminating the highly oxidation-susceptible molybdenum. On the other hand, it was equally not expected that the ductility of these welds should suffer from the use of the special gases as was the case of arc-cast molybdenum. Examination of Table 2 indicates that the results were as predicted. In spite of some scattering of the data, it is definitely established that the sintered molybdenum welds made in argon or hydrogen with an acceleration of 0.26 ips^2 were as ductile as those made in air. These results by themselves do not command much significance. However, they lend strong support to the belief that the additional loss of ductility in the arc-cast molybdenum welds made in argon or hydrogen over those made in air, was due to the difference in carbide precipitation for reasons given previously.

Summary

The results of this investigation have demonstrated that, under properly chosen conditions, flash welding can produce welds of acceptable ductility in arc-cast molybdenum. Since the welding is completed in a matter of a few seconds, oxidation of the joint is not as severe as in other conventional processes. Most of the oxides that are formed near the flashing interface are squeezed out by subsequent upsetting. In addition, the upsetting action also refines the recrystallized structure, reduces the porosity, and breaks up any oxide film which may have formed around the grains in the resulting joint. These advantages are not offered by most of the usual welding processes.

It is definitely clear that the ductility of molybdenum flash welds is critically influenced by platen acceleration and amount of upset. In the case of flash welding in air, some oxygen is bound to remain in the weld zone, since the limited plasticity of molybdenum forbids sufficient upset to remove the heat-affected zone completely. The amount of remaining oxygen is greater, the higher the temperature of the heat-affected zone and the longer the exposure of the zone to the elevated temperatures. It is for this reason that high platen accelerations, which produce fast platen movements and steep temperature gradients, are desirable. However, depending on the base material, specimen dimensions, and clamping distance, there appears to be a limit in platen acceleration beyond which any benefit described above is outweighed by the lowered plasticity of molybdenum. The importance of the plasticity lies in its relationship to the amount of upset. A minimum amount of upset is required to remove the major part of the oxides and porosity concentrated in the region near the flashing interface. Above this minimum upset, the ductility of the flash welds increases with increasing amount of upset in accordance with the effect of upsetting on the grain size, porosity, and oxide film in the resulting joint. When the upset is excessive, however, a severely fibered structure, oriented perpendicularly to that of the wrought base metal, is created in the weld center, providing planes of weakness which lead to early fracture of the weld in a bend test. For a given amount of upset, the degree of plastic deformation, and hence the severity of fibering, is an increasing function of platen acceleration, because of the diminishing plasticity of the metal associated with the steep temperature gradients of high platen accelerations.

In addition to oxidation and weldment fibering, grain-boundary precipitation of carbides also contributes to the embrittlement of the arc-cast molybdenum welds made in air. Since the precipitation depends on the cooling rate of the heat-affected zone, the extent of precipitation is greater at lower platen accelerations and smaller amounts of upset, both of which are inducive to slower cooling rates.

The effect of preferential carbide precipitation, while perhaps not very damaging in the welds made in air, appears to be one of the main sources of embrittlement in the case of the arc-cast molybdenum flash welds made in argon and hydrogen in the steel chamber. Whereas the sintered molybdenum flash welds made in these gases have about the same ductility as those made in air, the arc-cast molybdenum welds made in argon or hydrogen exhibit bend ductility inferior to that of the welds made in air. This is believed to be caused by the more extensive carbide precipitation in the welds made in the special atmospheres.

In brief, the results of this investigation serve to demonstrate further the complexity of welding molybdenum. To minimize oxidation, the welding process must be rapid or be conducted in a non-oxidizing atmosphere. The use of pressure in making the joint is

either essential or desirable. Inasmuch as the ductility of the joint depends on its structure, the application of pressure must be compatible with the physical properties such as plasticity of the metal under the prevailing conditions. The satisfaction of this compatibility, however, may easily entail the danger of retaining harmful amounts and distribution of oxides, porosity, grain coarsening, and carbides in the weldment. This dilemma makes it unlikely that very ductile welds of molybdenum can ever be produced in air. In the case of welding in a non-oxidizing atmosphere involving carbide precipitation, the influence of the welding atmosphere on the composition of the heat-affected zone, as well as the cooling effect of the welding apparatus on this zone, have to be taken into consideration. Added to these complications, of course, is the requirement that the process must be suitable for commercial applications.

Conclusions

1. Molybdenum welds of acceptable bend ductility were produced in both arc-cast and in sintered molybdenum by flash-welding in air.

2. Entrapped oxides at the weld interface, the creation of a transverse fiber structure during upsetting, and carbide precipitation in the weld heat-affected zone, all impaired the bend ductility of flash welds.

3. Insufficient upset always resulted in entrapped oxides at the weld interface causing inadequate bend ductility.

4. Increasing the upset distance up to an optimum value assisted in eliminating entrapped oxides in both grades of molybdenum and reduced the severity of carbide precipitation in the arc-cast molybdenum.

5. Excessive amounts of upset were found to produce a transverse fiber structure in the weld zone causing severe reduction in bend ductility.

6. Steep temperature gradients at the initiation of upset, produced by high rates of platen acceleration and short clamping distances, were found to localize the carbide precipitation and provide superior bend ductilities in the higher carbon arc-cast molybdenum.

7. No improvement in bend-ductility was obtained with either arc-cast or sintered molybdenum when tank argon or tank hydrogen atmospheres were employed during welding.

8. Flash welds made in arc-cast molybdenum showed the highest bend ductility when made in air, apparently a result of the decarburizing action of the oxygen.

Acknowledgments

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RESEARCH NEWS

(*Continued from page 250-s*)

Chicago plant. This original laboratory was utilized until an up-to-date building was completed on June 18, 1954.

The new building, a brick structure approximately 50 ft wide by 100 ft long and three stories high, consists of an office and working space. Approximately one-half of the building is under a crane area equipped with a 5-ton crane for handling large welding and testing work. Incorporated in the office space is a large class room for use in training and instructing foremen and welding supervisors. The building is also equipped with a complete metallurgical laboratory for determining the metallurgical effects on various metals during welding.

The field welding department deals primarily with techniques and procedures for the erection department. There are also comprehensive welding and metallurgical laboratories at the Chicago, Birmingham, Greenville and Salt Lake City plants to deal with similar problems in shop fabrication.

Fig. 5 Working area, equipped with an overhead crane, in the Field Welding Laboratory

Fig. 6 One of the Field X-ray units used for inspecting weldments during construction

HEADGEAR
Part No. 62

This headgear has been furnished on all Jackson fiber glass helmets and remains available.

It permits fitting to the head in ⅛" steps, clearly marked in hat sizes for quick, yet firm adjustment before putting the helmet on.

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NEW Jackson ADJUST-O-LOK

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The mechanism, entirely enclosed, smooth against the head, has a minimum of moving parts. Both *knob* and *gear* are of Nylon, lightweight, and non-conductive.

This new ADJUST-O-LOK Headgear is interchangeable with the No. 62 headgear, attaches to the same Jackson friction pivots, adjustable from the outside while in use. Plastic straps, of a new formula, are stronger, self-extinguishing. They're easy to clean. Cork-padded sweatband snaps on quickly, is inexpensive to replace.

CHOOSE FROM THESE JACKSON FIBER GLASS HELMETS . . .

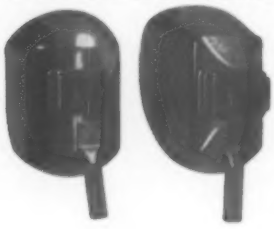
LIFT-FRONT type H-2
permits work inspection without raising entire helmet. Lens holder of high-impact thermosetting plastic has hinged door held by coil springs. Cover glass protects filter lens; another glass protects the eyes when front is raised.

FIXED-FRONT type H-3
of narrow-front design. All parts are interchangeable with type H-1. With metal or plastic lens holder.

LIFT-FRONT type H-4
This narrow-front, fiber-glass helmet has the same parts as type H-2, including plastic lens holder with hinged door for quick work inspection.

FIXED-FRONT type H-1
Available with metal lens holder or with the new, high-impact plastic lens holder as shown above.

—WITH EITHER ADJUST-O-LOK OR HEADGEAR NO. 62



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HANDSHIELDS H-5 and H-6

They consist of the same fiber glass shells as Helmets H-1 and H-3 respectively, and are fitted with new plastic insulated fixed-front lens retainers and vulcanized fiber handles.

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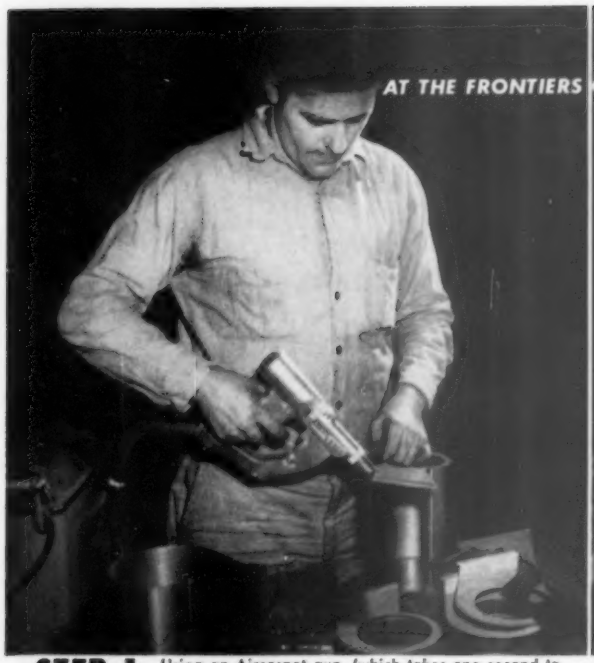
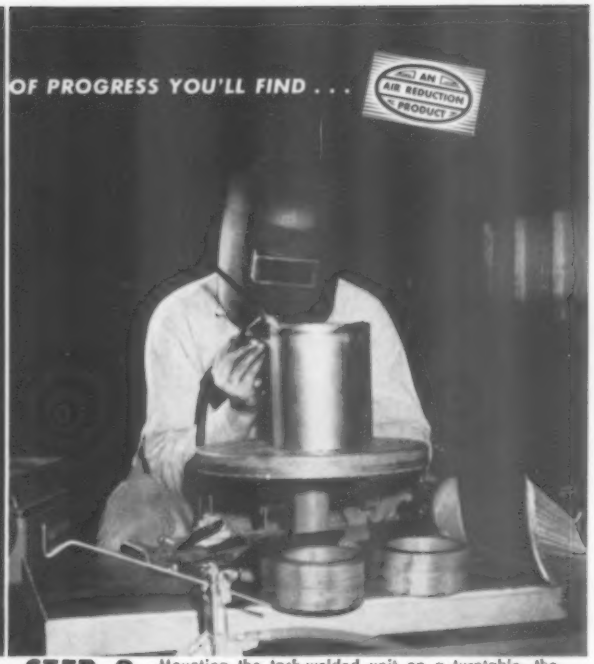


STEP 1. Using an Aircospot gun, (which takes one second to make a strong, sound spot weld), the Falstrom operator tack-welds flange on a metal cover. An average of 10 tacks are needed. The metal is 16 gauge mild steel.



STEP 2. Mounting the tack-welded unit on a turntable, the same operator exchanges the Aircospot gun for an HB-8 Heliweld holder. The Airco Heliweld process joins the circumferential seam at a speed of 16 inches per minute.

Falstrom Company
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...speeds seam-welding 75% with HELIWELDING!

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Previous methods of tack-welding required the use of jigs and fixtures — a procedure that hampered the operator and slowed production. Aircospot, however, tack-welds from just one side of the metal. It eliminates jigs and back-up plates, completely streamlining the work flow. At the same time, by using Heliwelding instead of oxyacetylene welding, Falstrom was able to reduce welding time 75%. This faster method of welding thin sections of metal provided further economies as the end product required less finishing and grinding.

One, or both, of these Airco inert-gas shielded arc welding processes can provide similar savings in your particular operation. Contact your local Airco Sales Representative or Authorized Airco Dealer for an on-the-spot demonstration in your plant — or — write Airco direct for complete information. Request Aircospot Catalog #2315, Heliwelding Catalog #2300.

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